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Evaluation of Groundwater Quality in Shallow Aquifers Under Cultivated Lands at Al Oha Area, United Arab Emirates

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EVALUATION OF GROUNDWATER QUALITY IN SHALLOW AQUIFERS UNDER CULTIVATED LANDS AT AL OHA AREA, UNITED ARAB EMIRATES

BY
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Faculty of Science
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Water Resources Management
Coastal Management
Remote Sensing
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ABSTRACT

To assess the impact of application of chemical fertilizers in agriculture on the Quaternary aquifer at Al Oha area, United Arab Emirates, 76 groundwater samples were collected during February 1995 - March 1996. Samples were analyzed for major, minor and trace chemical constituents in the Food Control Laboratory, Abu Dhabi.

The Total Dissolved Solids (TDS) of collected samples varied between 500 milligrams per liter (mg/l) in the east and 3,500 mg/l in the west. Except for bicarbonate ion (HCO_3^-), concentration of major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (CO_3^{2-}, SO_4^{2-} and Cl^-) shows a general increase from east to west. The increase of salinity and concentration of all ions from east to west occurs in the direction of groundwater flow, where ion-depleted water from recharge area in the east becomes progressively loaded with more ions towards discharge areas in the west.

Concentration of nitrate ion (NO_3^-) in groundwater within the study area during February 1995 - March 1996 remained below the limits recommended by the World Health Organization (WHO) for drinking water (45 mg/l as NO_3^- or 10 mg/l as NO_3^--N). Phosphate ion (PO_4^{2-}) shows trace concentrations in groundwater within the study area, averaging 0.8 mg/l. With the exception of few local anomalies, concentrations of iron (Fe), manganese (Mn), lead (Pb), zinc (Zn), copper (Cu), cobalt (Co) and chromium (Cr) shows a general increase from east to west.

Based on the above results, there is no reason to believe that the chemical fertilizers used on farm lands at Al Oha area has adversely affected groundwater in the Quaternary aquifer.

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INTRODUCTION

CHAPTER I

INTRODUCTION

The fast development in United Arab Emirates during the last three decades has lead to a rapid growth in the green cover in general and farm lands in particular. To increase crop productivity, chemical fertilizers are widely applied on farms. Excessive use of these fertilizers beyond the crop needs may lead to the downward movement of these chemicals, along with drainage water, towards shallow groundwater. Repeated use of chemical fertilizers and the free nature of main aquifers in United Arab Emirates, may have adversely affected shallow groundwater resources.

1.1 Location of the Study Area

The study area lies in the eastern part of the Emirate of Abu Dhabi along the border of the United Arab Emirates (U. A. E.) and Sultanate of Oman. The reconnaissance study of 1995 covered the area bounded by Longitudes 55° 20' and 55° 50' E and Latitudes 24° 10' and 24° 30' N (Figure 1), whereas the detailed study in 1996 was limited to the area between Longitudes 55° 40' and 55° 50' E and Latitudes 24° 15' and 24° 30' N (Figure 2).

1.2 Objectives

The main objective of this study is to investigate the effect of the use of chemical fertilizers in agriculture on groundwater of the Quaternary aquifer at Al Oha area, U. A. E. The specific objectives are: (1) to investigate the hydrogeological conditions of the area, (2) to characterize the groundwater chemistry and (3) to assess the effect of application of chemical fertilizers in agriculture, specifically NO_3^- and PO_4^{3-}, on groundwater.

1.3 Methods of Study

To achieve the above mentioned objectives, field work, laboratory analyses and office activities were achieved during the period from February 1995 to March 1997.

1.3.1 Field Work

a. The field work of this study was conducted during two rainy seasons, February 1995 and March 1996.

b. In February 1995, 46 groundwater samples were collected from shallow, private water wells tapping the Quaternary sand and gravel aquifer (Figure 1).

c. In March 1996, 30 groundwater samples were collected from shallow wells around Al Oha area (Figure 2).

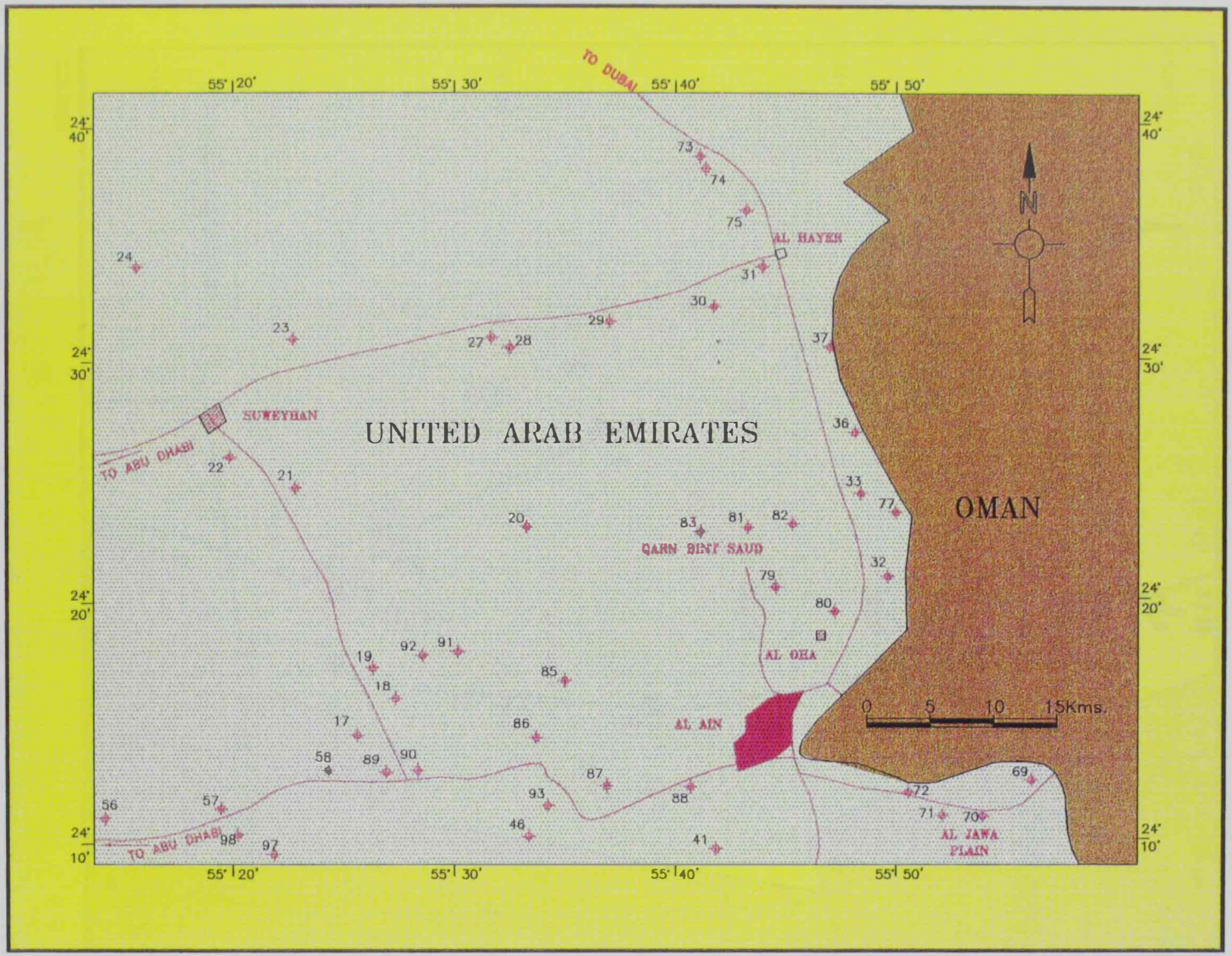

Figure 1. Location map of area investigated in Febrary 1995. Red circles represent water wells sampled for the present study.

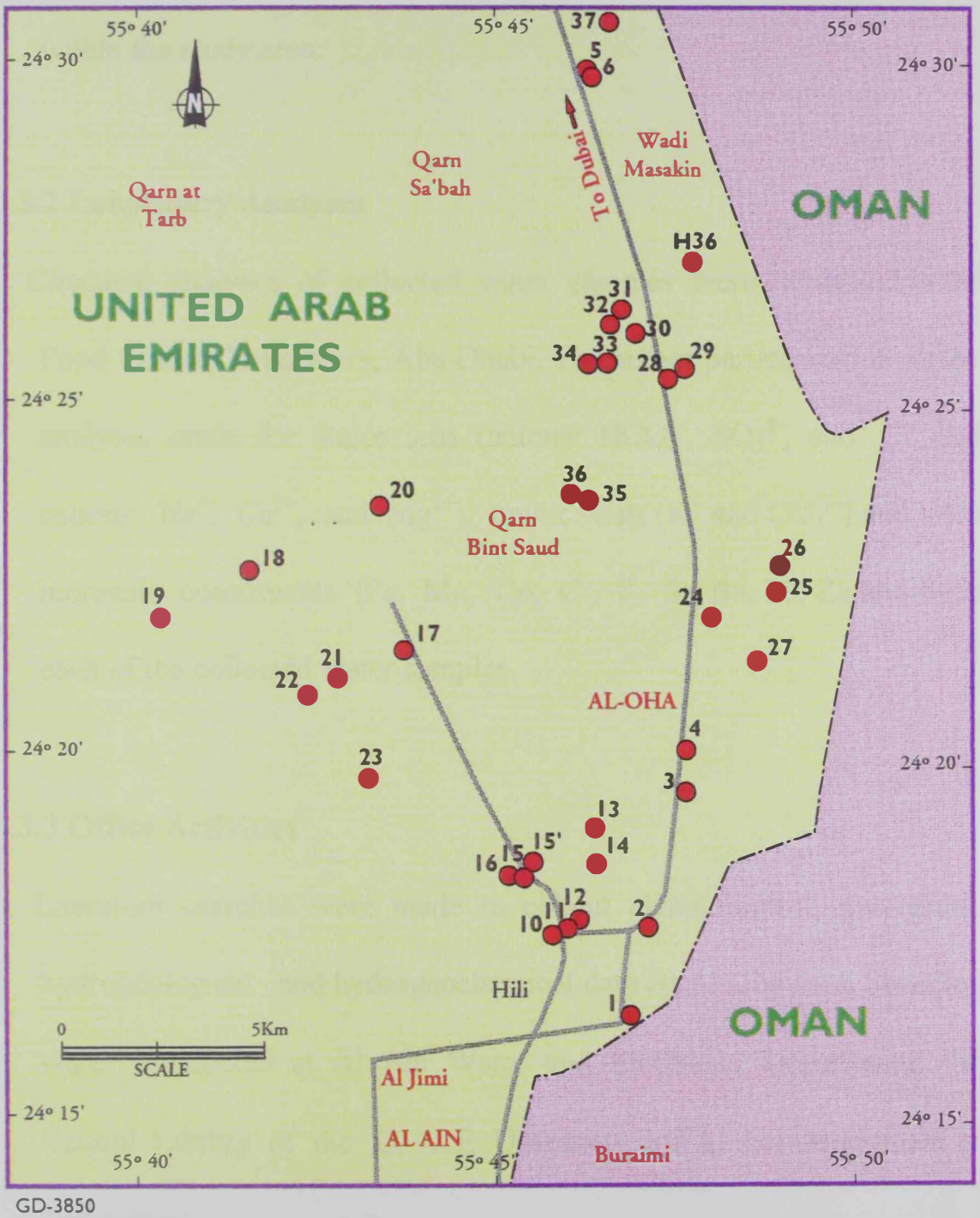

Figure 2. Location map of area investigated in March 1996. Red circles represent water wells sampled for the present study.

d. The local geological and geomorphological features within the study area were investigated for their possible influence on groundwater within the study area.

1.3.2 Laboratory Analyses

Chemical analyses of collected water samples were conducted in the Food Control Laboratory, Abu Dhabi. The author participated in all the analyses made for major ions (anions: HCO_3^-, SO_4^{2-}, and Cl^-, and cations: Na^+, Ca^{2+}, and Mg^{2+}), minor ions (K^+ and CO_3^{2-}) and trace inorganic constituents (Fe, Mn, Cu, Cr, F, Sr, Ba, Pb, Zn and B) in each of the collected water samples.

1.3.3 Office Activities

a. Literature searches were made to collect climatological, geological, hydrogeological and hydrogeochemical data on Al Oha area. Searches were conducted at Al Ain Water and Electricity Department, the Central Library of the U. A. E. University and Al Ain Department of Agriculture.

b. Analysis of the climatological data of Al Oha meteorological station for the period 1971-1995.

c. Presentation of the results of chemical analyses of water samples on relevant charts, graphs and diagrams.

d. Study and interpretation of the results of field and laboratory measurements and preparation of the final draft.

CHAPTER II

GEOMORPHOLOGY AND GEOLOGY

CHAPTER II

GEOMORPHOLOGY AND GEOLOGY

The study area is covered by a rock sequence ranging in age from the Cretaceous to the Quaternary times. The rock types, geological structures and the prevailing climate are the factors controlling the amounts of surface runoff and groundwater recharge in Al Oha area. In this study, special emphasis was given to the Quaternary sand and gravel aquifer at Al Oha area because its water is used for domestic as well as agricultural purposes.

The objective of this chapter is to describe the exposed rock types within the study area and evaluate their effect on groundwater chemistry in the Quaternary sand and gravel aquifer.

2.1 Geomorphology

In addition to field surveys; the study of topographic maps, aerial photographs and satellite images enabled recognition of the following geomorphic features in the study area: (1) mountains, (2) gravel plains and (3) sand dunes (Figure 3).

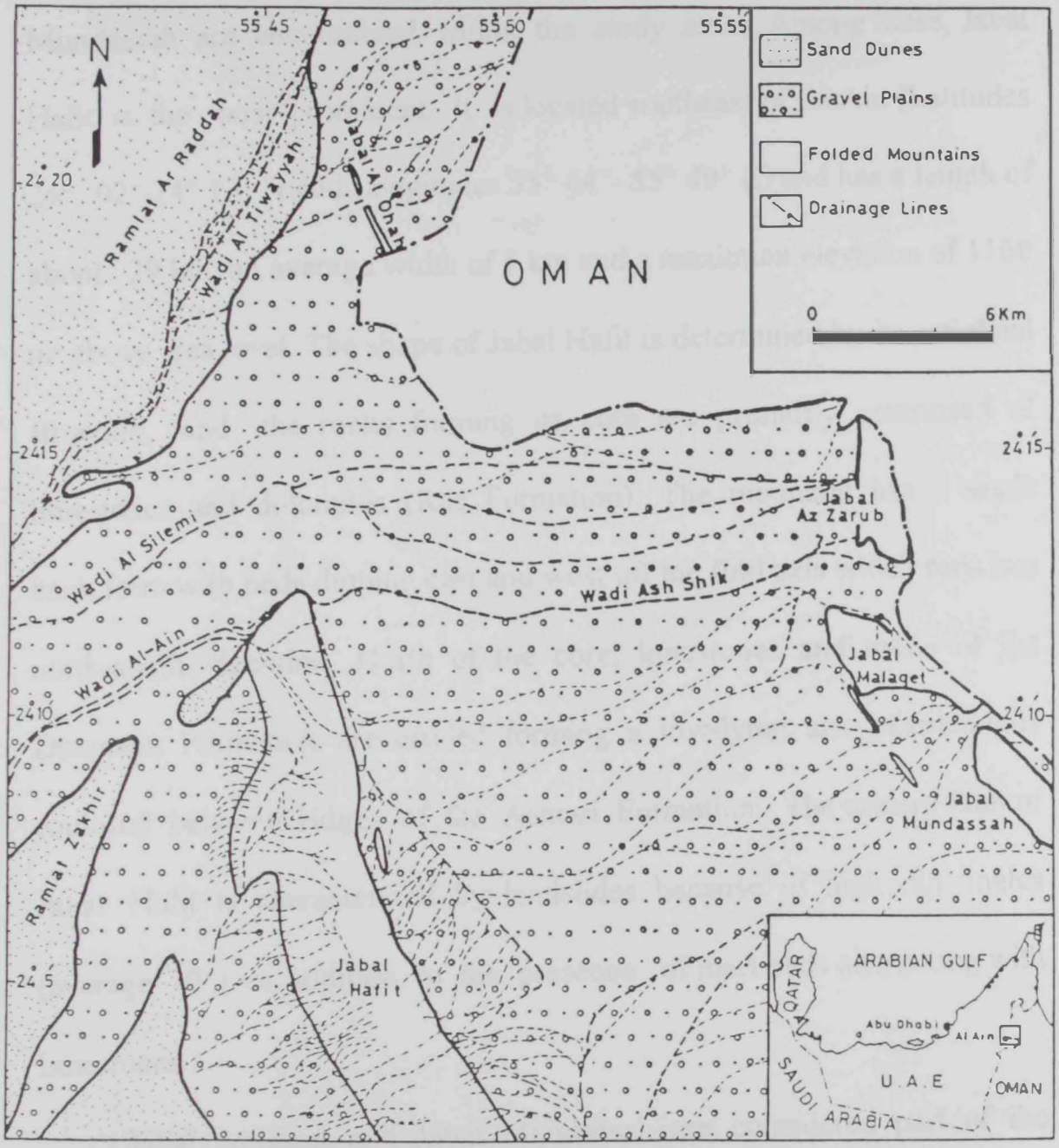

Figure 3. Geomorphological map of the study area, simplified from the 1993 National Atlas of United Arab Emirates (Antar, 1996).

2.1.1 Mountains

Jabal Hafit, Jabal Al Oha, Jabal Az Zarub, Jabal Malaqet and Jabal Mundassah are encountered within the study area. Among these, Jabal Hafit is the most prominent. It is located southeast of Al Ain (Latitudes 24° 02'-24° 13' N and Longitudes 55° 44'- 55° 49' E) and has a length of about 29 km, an average width of 5 km and a maximum elevation of 1160 m above sea level. The shape of Jabal Hafit is determined by its anticlinal structure, and the rocks forming its core are primarily composed of limestones and dolomites (Rus Formation). The mountain has a whale back form with beds dipping east and west off the fold axis which runs in a north-south direction. North of the core, limestones and marls of the Dammam Formation are eroded forming a low-lying area of small hills enclosed between ridges of the Asmari Formation. The eastern limb of Jabal Hafit is characterized by landslides because of high dip angles (average 70°) in addition to the presence of marl beds alternating with limestones.

Jabal Malaqet and Jabal Mundassah are considered part of the Oman Mountains and are located approximately 17 km east of Jabal Hafit. The two mountains form asymmetrical anticlinal structures with their eastern limbs forming the main part of the exposures. The western limbs form disconnected strike ridges and are more subdued. These mountains

receive a relative high rainfall and represent the recharge area for the Quaternary sand and gravel aquifer in Al Oha and Al Ain areas. The low dissolution of hard ophiolitic rocks forming Jabal Malaqet and Jabal Mundassah is responsible for the excellent-quality groundwater in the eastern part of the study area.

Jabal Al Oha lies 8 km northeast of Al Ain city. It consists of three NW-SE parallel hogback ridges averaging about 10 km in length. The ridges represent fault repetitions of the western limb of the horseshoe-shaped southerly-plunging anticline of Jabal Huwayah exposed further east.

2.1.2 Gravel Plains

Within the study area, gravel plains bound the eastern side of the Oman Mountains. These plains occupy the area between the Oman Mountains to the east and the sand-dune fields in the west. The plains have a gentle slope from east to west with an average gradient of 0.001 (Ghoneim, 1991).

In the study area, the gravel plains primarily consist of alluvial sands and gravels transported by wadis dissecting the Oman Mountains. The continuity of these plains is locally interrupted by sand dunes. Wadi Tuwayyah transverses the gravel plain in a NE-SW direction. A prominant alluvial fan occurs east of Al Oha (Photo 1).

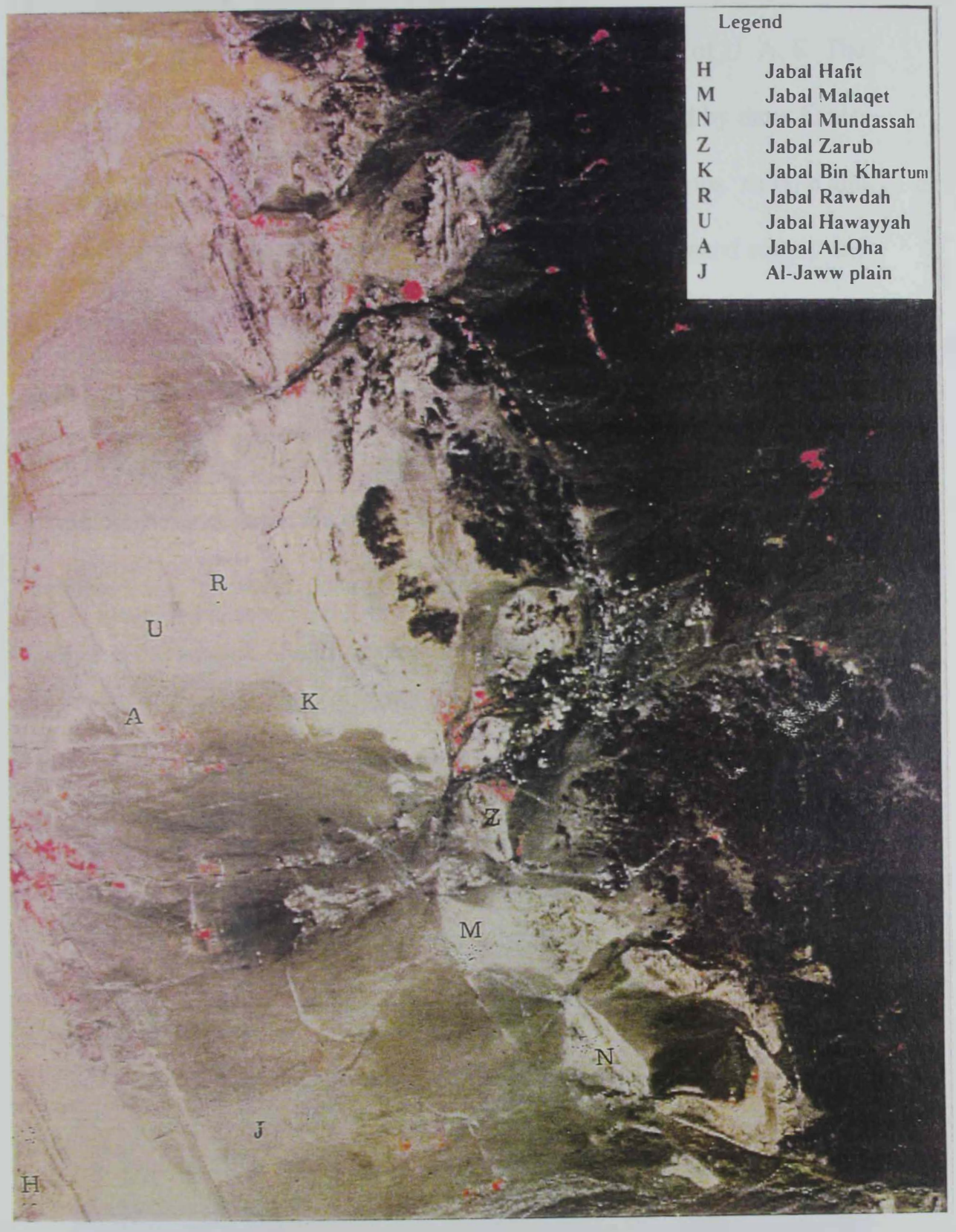

Photo 1. The main rock outcrops in the eastern and southeastern parts of the study area (Al Shamsei, 1993).

2.1.3 Sand Dunes

Sand dunes cover about 75% of the surface area of U. A. E. The northern and western parts of Al Oha area are dominated by dune fields. Embabi (1991) attributed the regional and local variations of type and pattern of sand dunes to variation in the wind regime, sand supply and local relief. The dominant dune type within the study area is the linear dunes. Linear dunes occupy the northern and western parts of the study area and extend in NE-SW and ENE-WSW directions. These dunes are dense and rather dark in colour towards the east due to mineralogical contributions by the exposures of ophiolitic rocks, and more lighter in the west as the amount of carbonate debris derived from Jabal Hafit increases (Photo 2).

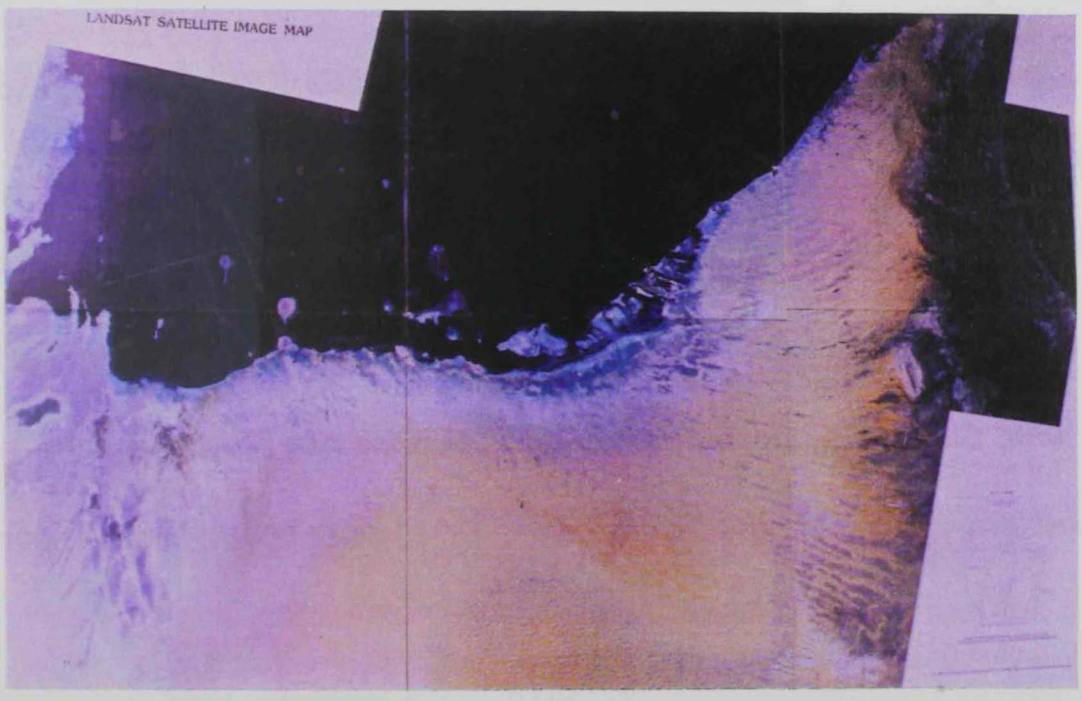

Photo 2. Landsat mosaic of the eastern part of U. A. E., showing linear dune patterns.

2.2 Stratigraphy

Al Oha area is dominated by rocks ranging in age from Upper Cretaceous to Holocene. Based on the work of Hamdan and Bahr (1992), the following subsections present a brief description of the surface stratigraphic column, from base to top (Figures 4 and 5).

2.2.1 Semail Ophiolite

Pre-Maastrichtian serpentinite and serpentinized peridotite of the Semail ophiolite represent the oldest rocks exposed in the eastern part of the study area. These rocks form the base of Jabal Malaqet and Jabal Mundassah in the southeastern part of the area (Photo 1).

2.2.2 Qahlah Formation

In Jabal Al Oha, the Qahlah Formation is represented by gray to green mudstone and shale capped by a 3-m thick unit of red-coloured, chert, pebble conglomerate. These sediments unconformably overly the Pre-Maastrichtian serpentinite and serpentinized peridotite, and are unconformably overlained by white limestone of the Simsima Formation.

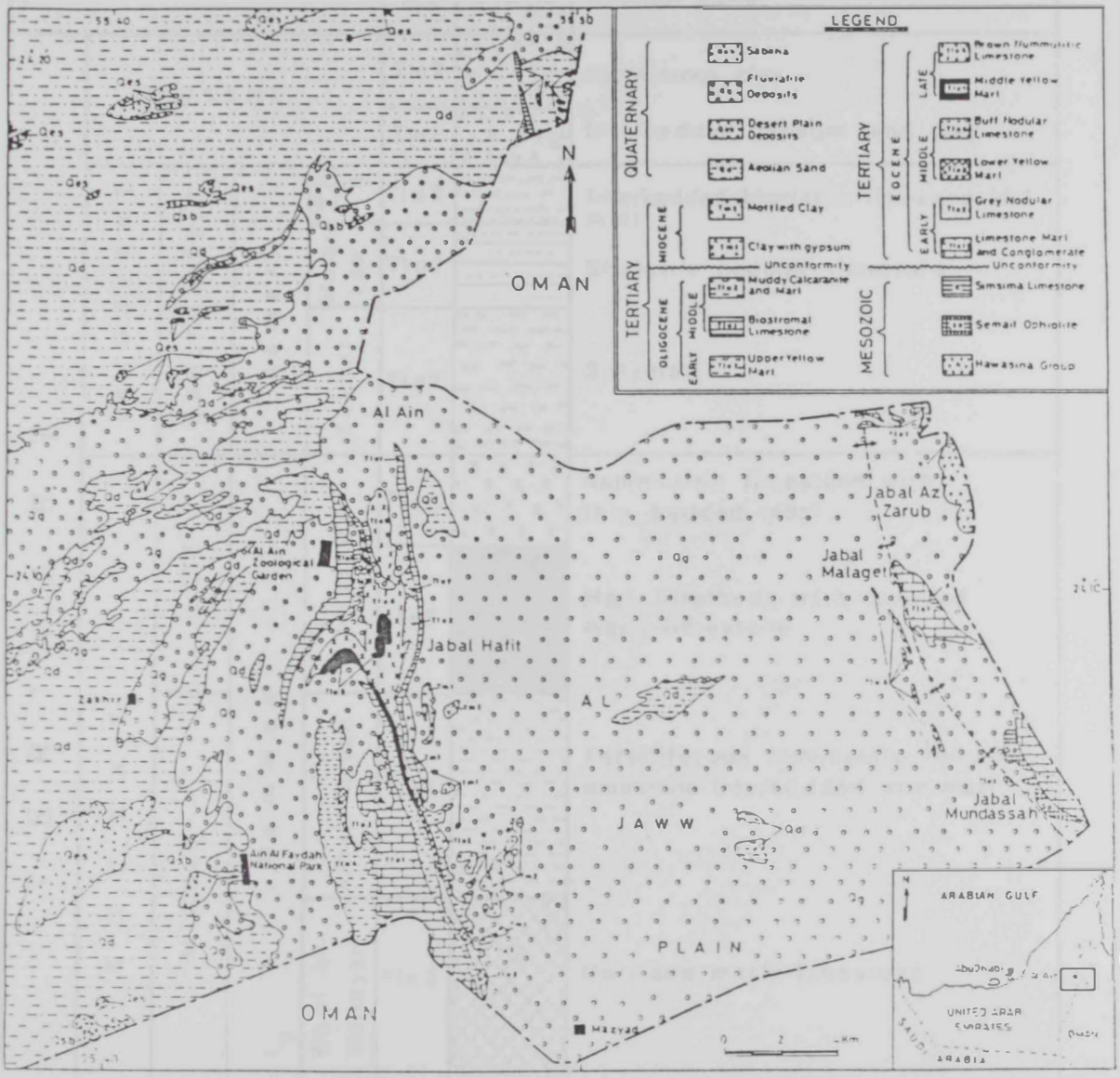

Figure 4. Geological map of Al Ain area compiled by Antar (1996) from Hunting (1979) and Whittle and Alshrahan (1994).

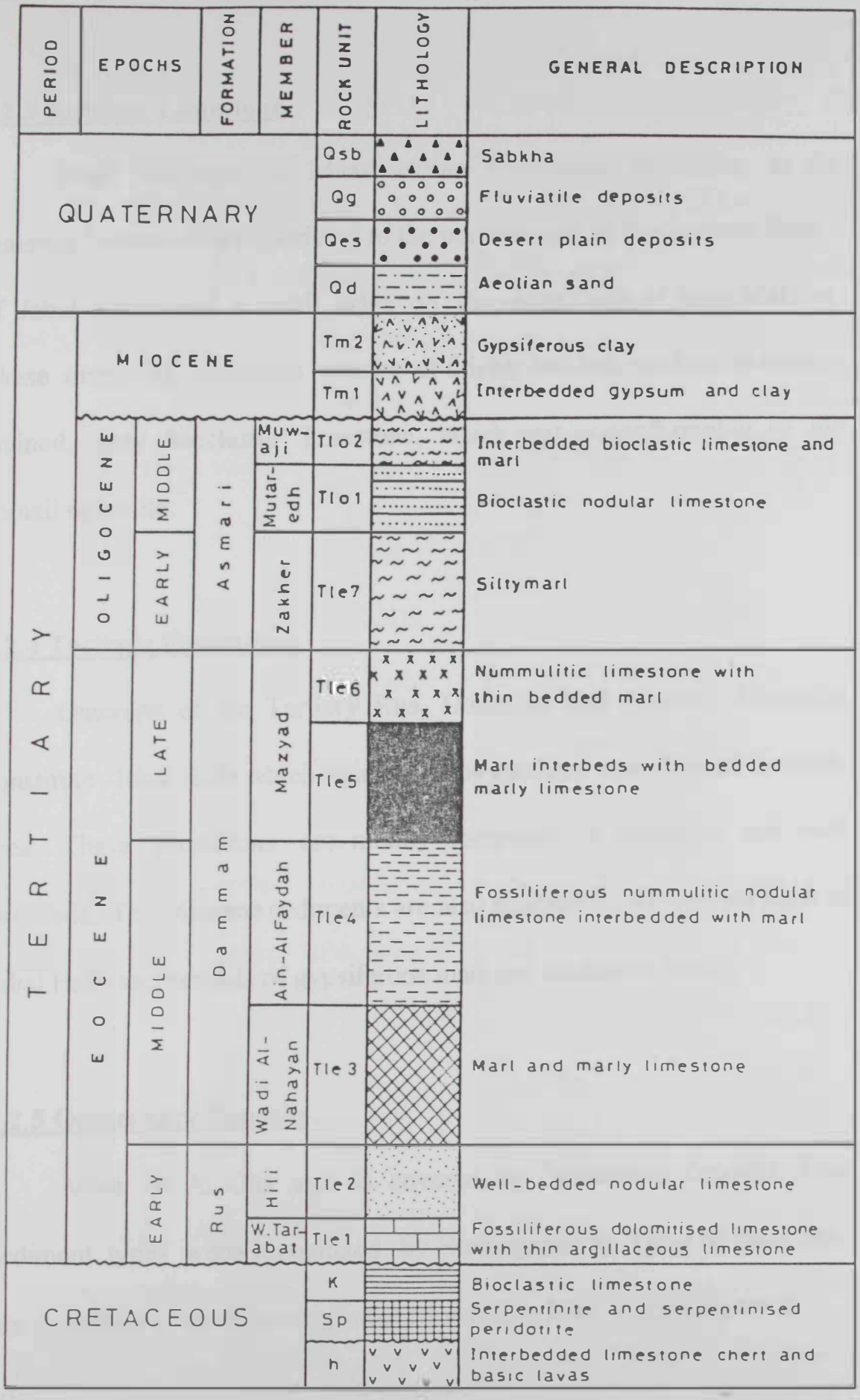

Figure 5. A composite surface stratigraphical column of the study area, modified by Antar (1996) from Whittle and Alshrahan (1994).

2.2.3 Simsima Limestone

Small outcrops of Maastrichtian limestones belonging to the Simsima Formation are restricted to the northern end of the western flank of Jabal Zarub and a small ridge on the eastern side of Jabal Malaqet. These limestone exposures consist of thickly bedded, medium to coarse-grained, gray bioclastic limestone, which rest unconformably on the Semail ophiolite.

2.2.4 Tertiary Formations

Outcrops of the Tertiary Rus, Dammam and Asmari formation constitute Jabal Hafit which represents the southern boundary of the study area. These formations are mainly composed of limestone and marl interbeds. The Miocene sediments are also exposed on the eastern flank of Jabal Hafit as interbeds of gypsiferous marl and mudstone bands.

2.2.5 Quaternary Deposits

Most of Al Oha area is covered by Quaternary deposits. Four sediment types were recognized by Hunting (1979). Three of these units are described in the following subsections, from base to top (Figure 5):

2.2.5.1 Aeolian Sand (Qd)

Sand dunes cover the northwestern and western parts of the study area. The colour of dune-forming sand changes from red and pink in the east to a more lighter colour westwards. The dune sediments are well-rounded grains of quartz and carbonate with minor proportions of basic and ultrabasic grains. Sorting is generally poor and no pure silica sands were observed.

2.2.5.2 Desert Plain Deposits (Qes)

These deposits occur between dune ridges in the west and north of the study area. These deposits are inter-layered laminated silts, carbonate cemented and locally show dune bedding. These rocks represent paleodunes which have been cemented by gypsum at times of higher water table and have been subsequently re-exposed by ablation. Sections exposed in barrow pits near Jabal Muhayjir, north of the study area, show inter-layered gravel, calcrete, nodular limestone and calcareous silt.

2.2.5.3 Fluvial Deposits (Qg)

Alluvial deposits occur beneath the piedmont plains fingering the Oman Mountains and Jabal Hafit. These deposits range from boulder gravel to conglomerate in the east and fine sand to silt further west. A

typical section in the alluvium of Al Jaww plain consists of pebbles and cobbles of gabbros, serpentinite, limestone and chert set in fine-grained matrix of carbonate silt. At some localities, pebbles are uncemented or loosely held together by coarse-grained recrystallized calcite. These rocks are both porous and permeable and make excellent aquifers. Towards Al Ain city and further west, the gravel and conglomerate are replaced by inter-bedded sand, silt and calcrete which tend to be more cemented than conglomerate. The calcrete is typically white, lacks obvious bedding, contains scattered grains of altered igneous rocks and irregular fracture surfaces coated with iron and manganese oxides.

CHAPTER III

HYDROGEOLOGY

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HYDROGEOLOGY

The objectives of this chapter are to investigate the prevailing climatic conditions in Al Oha area, nature of the Quaternary sand and gravel aquifer and surface water - groundwater relationship.

3.1 Climatic Conditions

Climatological data obtained from the Ministry of Agriculture and Fisheries and those of Al Oha meteorological station for the period 1971-1995 were used to investigate the climatic conditions of the study area. The studied climatic elements include: (1) solar radiation [mwh/cm^2], (2) air temperature [°C], (3) relative humidity [%], (4) wind speed [km/hr], (5) pan evaporation [mm/day] and (6) rainfall [mm/month]. The following is a brief discussion on each of these elements:

3.1.1 Solar Radiation

The U. A. E. receives the highest solar radiation (796 mwh/cm^2) in June and the lowest (425 mwh/cm^2) in December, with a general increase from December to June and decrease from July to September. The average

annual hours of sunshine in U. A. E. is 10 hours per day, with a maximum of 11.5 hours in May and a minimum of 8.4 hours in December (Al Shamesi, 1993). The high intensity of solar radiation in the study area increases water loss through evapotranspiration.

3.1.2 Air Temperature

The mean monthly air temperature in the study area varies between 17°C in winter and 35.7°C in summer, and the mean annual air temperature is 27°C. The coldest month is January and the hottest month is July. The season of high air temperature extends from April to September. The air temperature is uniform across the study area, varying between 27°C in Abu Dhabi and 28°C in Al Oha and Al Hayer.

3.1.3 Relative Humidity

Generally, the relative humidity in the U. A. E. attains its maximum value during the November-March period, and its minimum value in May. The mean annual relative humidity in the Abu Dhabi is about 60%, decreasing east to 45% near Al Ain and southwest to 20% near Liwa. In the study area, relative humidity varies between 45% in the east and 55% in the west.

3.1.4 Wind Speed

Generally, wind speed over the study area tends to be light to moderate with an annual mean of 18.5 kilometers per hour (kph), decreasing from north-northwest to south-southeast (Al Shamesi, 1993). The Shamal wind reaches its maximum speed (41 kph) in the spring between March and August. October (fall), on the other hand, has the lowest records of wind speed (2 - 6 kph).

3.1.5 Pan Evaporation

The type of evaporation pan used in the meteorological stations is a U. S. Class-A pan. The average pan coefficient determined for the U. A. E. is 0.6 (Ministry of Agriculture and Fisheries, 1993). The mean daily pan evaporation for the study area is 10 mm.

3.1.6 Rainfall

The average annual rainfall in the U. A. E. is 119 mm. However, in wet years, for example, 1981-1982, the mean annual rainfall was 282 mm, reaching more than 450 mm in some mountainous areas. In 1995-1996, rainfall recorded in Al Oha meteorological station was 200 mm. In dry

years, for example, 1983-1984, the mean annual rainfall was only about 40 mm in Abu Dhabi.

Based on records of eight meteorological stations for the period 1971-1992, Antar (1996) constructed an iso-hyetal map for Al Ain area (Figure 6). This figure shows that the mean annual rainfall ranges from less than 70 mm east of the Abu Dhabi International Airport to more than 140 mm in Masfut in the northeast. It also shows that the annual average rainfall on Al Oha area is about 65 mm.

3.2 Hydrogeologic Conditions

Al Oha area lies in an arid belt characterized by low rainfall and high evapotranspiration. The main objectives of this section are to study the nature and hydraulic properties of the Quaternary sand and gravel aquifer in Al Oha area, which control the surface water - groundwater relationship.

3.2.1 Surface Water

The mean annual runoff from the main wadis in U. A. E. during the rainy season is about 120 million m^3 (Al Asam, 1995). Within the study area, the main wadi which can carry water during heavy rain storms is Wadi Tuwayyah which runs from Oman mountains in the northeast,

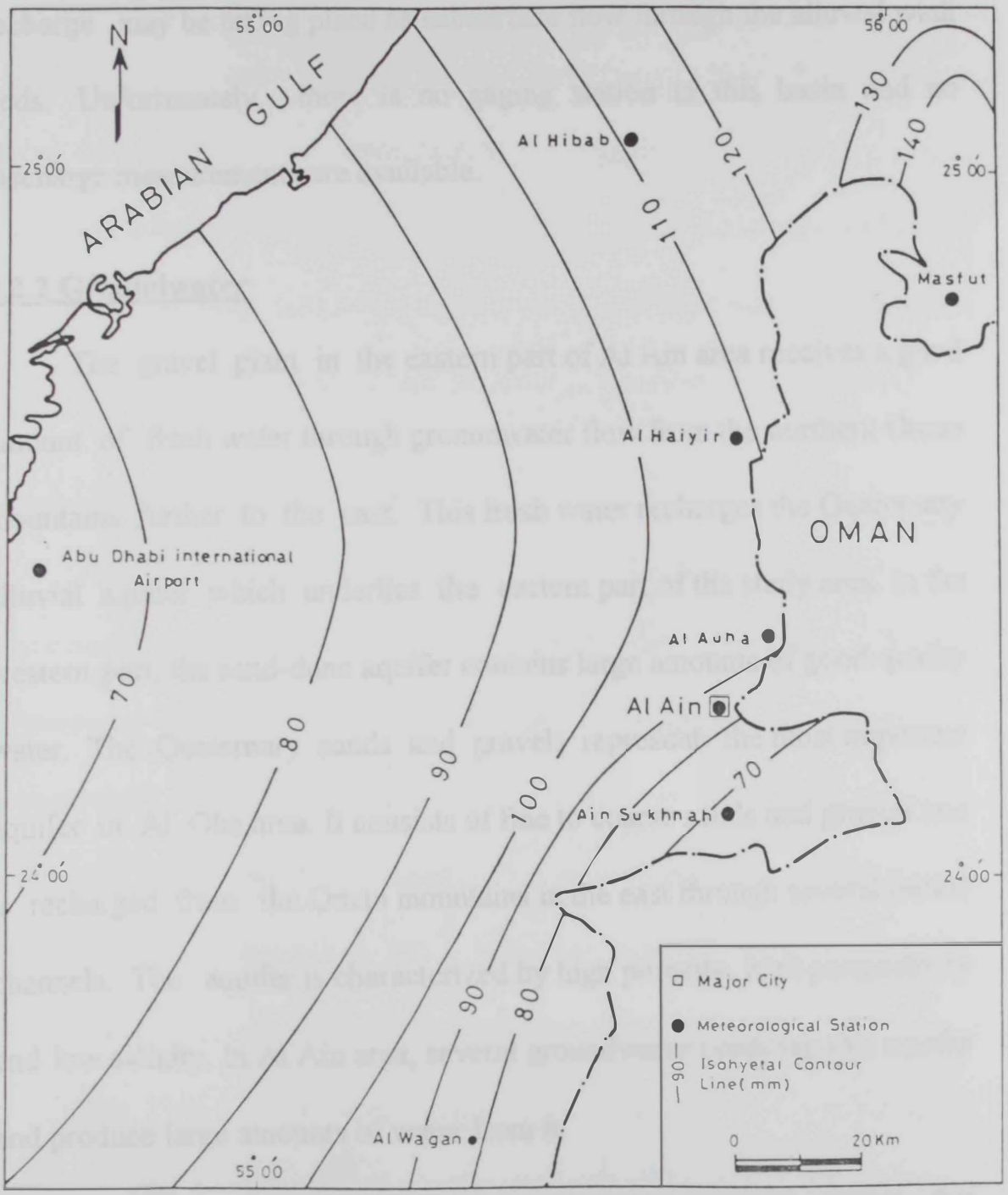

Figure 6. Iso-hyetal (mm) contour map of the Al Ain area for the period 1971-1992 (Antar, 1996).

across the gravel plain, to the sand-dunes fields in the southwest. In the present, this wadi does not carry surface runoff. However, groundwater recharge may be taking place as subsurface flow through the alluvial wadi beds. Unfortunately, there is no gaging station in this basin and no discharge measurements are available.

3.2.2 Groundwater

The gravel plain in the eastern part of Al Ain area receives a good amount of fresh water through groundwater flow from the northern Oman mountains further to the east. This fresh water recharges the Quaternary alluvial aquifer which underlies the eastern part of the study area. In the western part, the sand-dune aquifer contains large amounts of good-quality water. The Quaternary sands and gravels represent the most important aquifer in Al Oha area. It consists of fine to coarse sands and gravels and is recharged from the Oman mountains in the east through several buried channels. The aquifer is characterized by high porosity, high permeability and low salinity. In Al Ain area, several groundwater fields tap this aquifer and produce large amounts of water from it.

The Quaternary sediments are represented by gravel and conglomerate outhwash fans deposited by flood flows from the Oman Mountains. These outhwash fans cover older geologic units and infill shallow depressions resulting in a relatively featureless plain sloping from

east to west. These sediments thicken toward the west and as much as 400 m of sediments were encountered in a borehole in the western side of Jabal Hafit (Gibb and Partners, 1970).

The Quaternary deposits become fine-grained toward the west away from the mountain source area, thereby reducing their potential as a source of good-quantity or quality groundwater. The Quaternary sediments represent the only significant aquifer in Al Oha region and the main regional source of fresh and brackish water in the Abu Dhabi Emirate.

3.2.2.1 Hydraulic-Head Map

Based on his field work in March 1996 and well-logs data, Garamoon (1996) constructed a depth to groundwater map for the Quaternary aquifer of Al Ain area (Figure 7). This map shows the depth to groundwater in Al Oha area is about 30 m below the ground surface, increasing to the north and south. The continuous increase of depth to groundwater in Suweyhan (50 m) and Al Ain (90 m) is a result of excessive groundwater pumping for different purposes.

The 1995 hydraulic-head map of the Quaternary aquifer in the study area indicated the presence of two major cones of depression centered east of Suweyhan and west of Al Ain areas. The presence of these cones reflects the effect of heavy groundwater abstraction on groundwater levels within the study area.

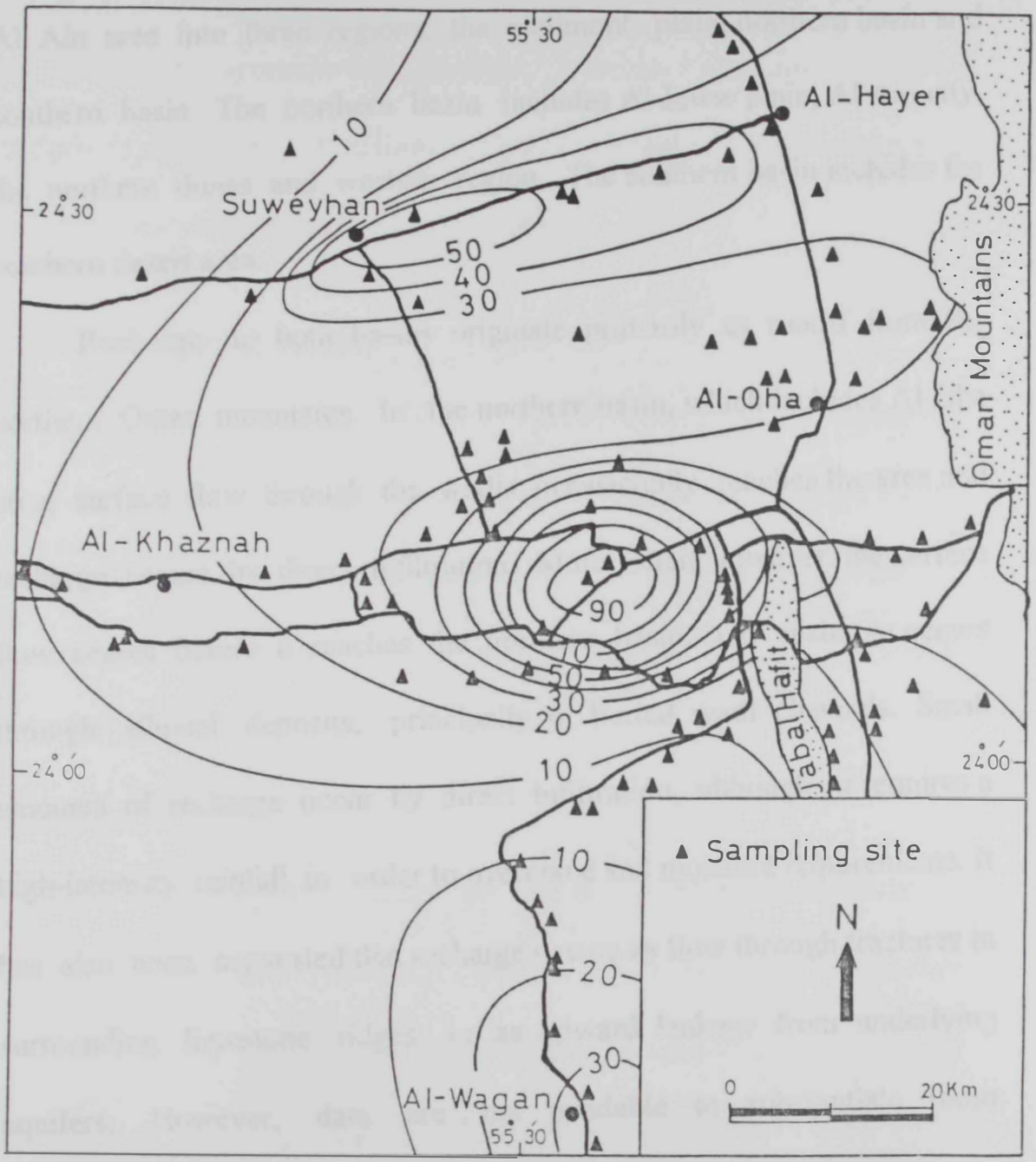

Figure 7. Depth-to-water (m) contour map of the Quaternary aquifer in Al Ain area in February 1995 (Garamoon, 1996).

3.2.2.2 Groundwater Recharge

For estimating groundwater recharge, Hyde (1992), subdivided Al Ain area into three regions: the piedmont plain, northern basin and southern basin. The northern basin includes Al Jaww plain, Al Ain city, the northern dunes and western region. The southern basin includes the southern desert area.

Recharge to both basins originate primarily as runoff from the northern Oman mountains. In the northern basin, which includes Al Oha area, surface flow through the wadis occasionally reaches the area and recharge occurs by direct infiltration. More often, however, the surface flow ceases before it reaches the northern basin, and recharge occurs through alluvial deposits, principally in buried wadi channels. Small amounts of recharge occur by direct infiltration, although it requires a high-intensity rainfall in order to overcome soil moisture requirements. It has also been suggested that recharge occurs as flow through fractures in surrounding limestone ridges or as upward leakage from underlying aquifers. However, data are not available to substantiate these assumptions.

Based on a 155 mm mean annual rainfall, a catchment area of 1460 km^2, type of sediments, porosity of surface sediments, topographic slope and that 10-15% of rainfall will recharge the Quaternary aquifer in the

northern basin, Hyde (1992) estimated the recharge to northern basin of Al Ain area as 15 million m^3/yr.

Hyde (1992) also estimated the recharge to the southern Al Ain basin based on groundwater gradient, transmissivity and length of boundary to be about 14 million m^3/yr. Therefore, the total recharge to Al Ain area may approximate 29 million m^3/yr.

3.2.2.3 Groundwater Storage

In his work on U. A. E., Hyde (1992) estimated the total storage of fresh water in the Quaternary aquifer of Al Ain area to be 2,600 million m^3 and the total storage of brackish water to be 18,000 million m^3. Therefore, the estimated total storage of fresh and brackish water in Al Ain area is 20,600 million m^3.

3.2.2.4 Groundwater Discharge

It is interesting to mention that the decline of groundwater levels started as early as 1966 (Gibb and Partners, 1970). However, this decline was only about 2 m in areas where heavy groundwater pumping for irrigating date palm groves and orchards gardens took place. Since 1970, the abstraction of groundwater in Al Ain area has increased excessively, mainly through wells equipped with mechanical pumps. Numerous well fields exist, some having as many as 100 wells. Very few of the well fields, and even less of the agricultural and private wells are metered.

The two major water users in Al Ain area are the Water and Electricity Department (WED) and the Agriculture and Forestry Department (AFD) of the Municipality. The WED utilizes exclusively fresh water, whereas AFD uses both fresh and brackish water (Table 1). The 1995 hydraulic-head map constructed by Garamoon (1996) for the Quaternary aquifer within the study area shows that the decline in groundwater levels has reached 50 m in the central zone of Al Ain city (Figure 8).

Table (1) shows that the agriculture, forestry and municipal landscaping accounted for 95% of the overall groundwater abstraction at Al Ain region in 1985. It also shows that human uses accounted only for 19% of the fresh-water consumption in the Al Ain area in 1985.

Table 1. Groundwater abstraction from the Quaternary aquifer in the Al Ain area in 1985 (Hyde, 1992).

User	Purpose	Fresh Water (Million m^3/yr)	Brackish Water (Million m^3/yr)	Total (Million m^3/yr)	Percent of Total
Water and Electricity Department	Domestic	11.8	0	11.8	
	Municipal	10.5	0	10.5	10.5
	Landscaping	24.1	0	24.1	
Agriculture Department	Irrigation	70.0	279.0	349.0	78.7
Forestry Department	Irrigation	0	48.0	48.0	10.8
Total		**116.4**	**327.0**	**443.4**	**100**

Since 1985, Al Ain region has grown rapidly and municipal landscaping, agriculture and forestry have greatly increased. The 1991

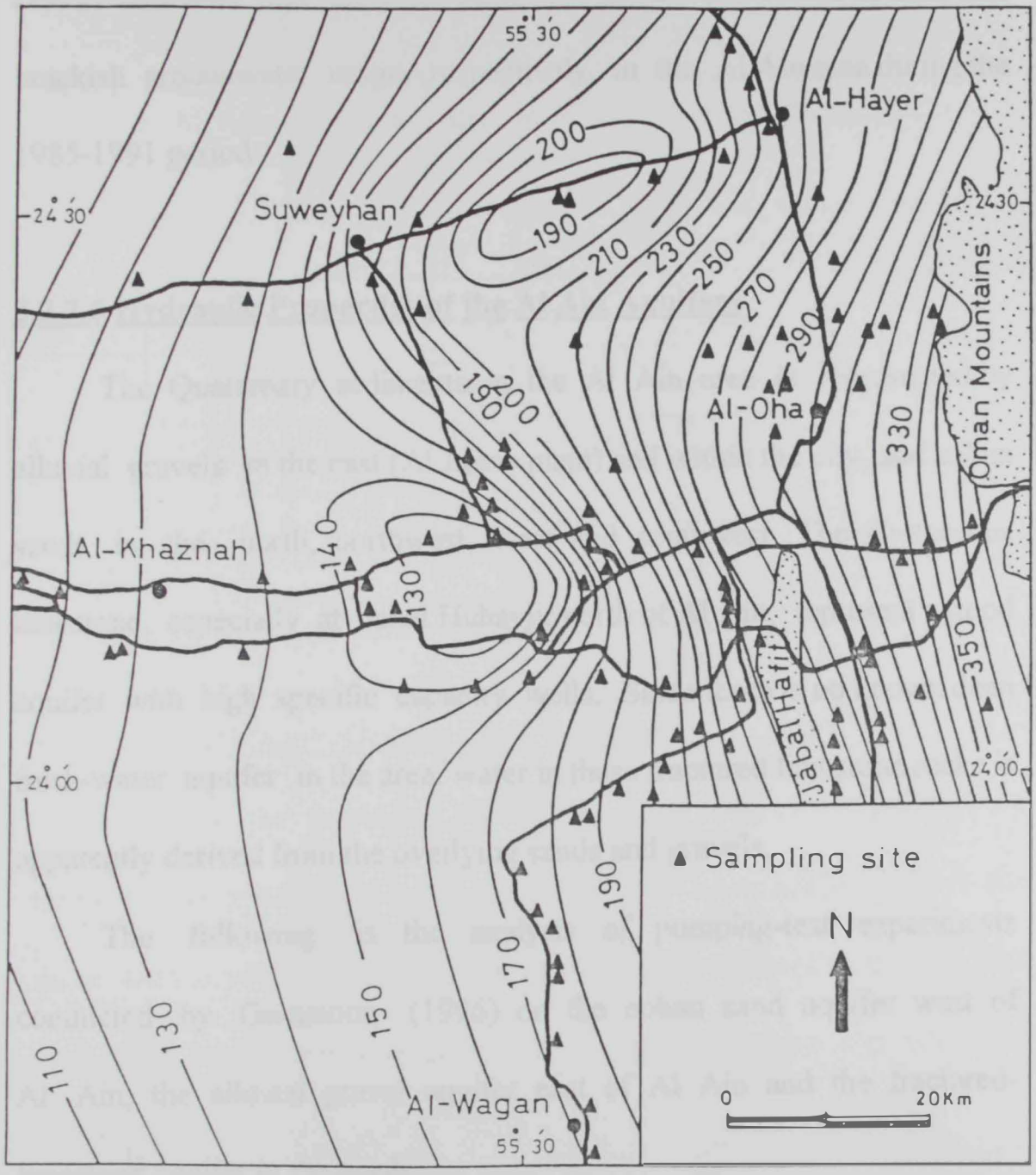

Figure 8. Potentiometric-surface map (in meters relative to sea level), based on water levels measured in 1995 and well-log data (Garamoon, 1996).

water use is significantly higher than the 1985 data listed above. Hyde (1992) indicated that there has been 27% and 80% increases in fresh and brackish groundwater usage, respectively, in the Al Ain area during the 1985-1991 period.

3.2.2.5 Hydraulic Properties of the Al Ain Aquifers

The Quaternary sediments in the Al Ain area is represented by alluvial gravels in the east (Al Jaww plain) and within the city, and eolian sands in the north, northwest, west and southwest. The Cretaceous limestone, especially at Jabal Huhayjir north of Al Ain, represent a good aquifer with high specific capacity wells. Since there is no known deep fresh-water aquifer in the area, water in these fractured limestone rocks is apparently derived from the overlying sands and gravels.

The following is the analysis of pumping-test experiments conducted by Garamoon (1996) on the eolian sand aquifer west of Al Ain, the alluvial gravel aquifer east of Al Ain and the fractured-limestone aquifer in the north.

The purpose of this analysis was to determine the hydraulic properties of Al Ain aquifers, which include transitivity (T) and storativity (S). The methods applied are Theis (1935), Jacob (1946) and Hantush

(1962). The results of application of the above methods for the aquifers of Al Ain area are listed in Table (2).

Table 2. Transmissivity (T) and storativity (S) values of the main aquifer in the Al Ain area, calculated by Theis (1935), Jacob (1948) and Hantush (1962) methods (Garamoon, 1996).

Aquifer	Parameter	Method				
		Tacob	Theis	Hantush	Recovery	Remarks
Eolian sand	T	42	37	76		
	S	4.9 E-3	4.2 E-3	3.0 E-2		
Alluvial gravel	T	5312	40	115	5501	r = 0.5 meters
	S			9.2 E-4		
	T	5074	4212	5136	4226	r = 15 meters
	S	3.7 E-4	6.5 E-4	4.6 E-4		
	T	5953	4642	5019	3208	r = 30 meters
	S	5.6 E-4	6.7 E-4	9.4 E-4		
Fractured limestone	T	519	505	425		
	S	2.6 E-7	3.3 E-7	1.5 E-6		

3.2.3 Surface Water - Groundwater Relationship

Because the prevailing climate within the study area is arid and the mean annual potential evapotranspiration (PET) is much greater than the mean annual rainfall, monthly and daily water surpluses associated with occasional heavy rain storms acquire a great importance in groundwater recharge.

According to the method described by Boonstra and de Ridder (1981), groundwater recharge (R) of the Quaternary aquifer in Al Ain area was calculated by Garamoon in 1996. He concluded that a mean annual rainfall greater than 140 mm can cause groundwater recharge in Al Ain

area. In contrast, no groundwater recharge is expected if the mean annual rainfall is less than 140 mm. Inspection of the rainfall data of Al Oha meteorological station for the period 1971-1995 shows that the annual rainfall that can contribute to groundwater recharge occurs once every four to five years. This recharge is more likely to occur during cycles with the same time intervals of above-average rainfall.

Based on field measurement of infiltration capacity (I_c) of sand dunes and interdune areas, Garamoon (1996) concluded that the infiltration capacity of sand dunes is three to six times those of the interdune areas and gravel plains. He also noticed that the infiltration capacity of both dune and interdune areas increases from east to west in the direction of increasing sorting and decreasing the uniformity coefficient of sediments.

CHAPTER IV

HYDROGEOCHEMISTRY

CHAPTER IV

HYDROGEOCHEMISTRY

The objectives of this chapter are to study the distribution of major, minor and trace chemical constituents of groundwater in the Quaternary aquifer of Al Oha area; to investigate the effect of climatological conditions, geological setting, hydrogeological regime and agricultural activities on groundwater chemistry and quality; and to evaluate the suitability of groundwater in the study area for different purposes.

For this study 76 groundwater samples were collected from private wells tapping the Quaternary aquifers in the study area during February 1995 (Figure 1) and March 1996 (Figure 2). The electrical conductance (EC) (μS/cm), water temperature (°C), hydrogen-ion concentration (pH) and total dissolved salt (TDS) contents in milligrams per liter (mg/l) were measured directly in the field. The samples were then analyzed for major cations (K^+, Na^+, Mg^{2+} and Ca^{2+}), anions (CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^- and NO_3^-) and trace metals (Fe, Mn, Cu, Cr, Sr, F, Ba, Pb, Zn and B) in the Food Control Laboratory, Abu Dhabi.

Results of complete chemical analyses of water samples collected from the study area in February 1995 and March 1996 are listed in Appendices A and B.

4.1 Analytical Techniques

The complete chemical analysis of the water samples was conducted in the Food and Environment Control Center, Abu Dhabi Municipality, Abu Dhabi. Different techniques have been employed for analysis. The following is a brief description of each of the analytical methods used in the present work:

4.1.1 Inductively Coupled Plasma (ICP)

A Perkin-Elmer Plasma-400 Emission Spectrometer was used for the analysis of some major (Ca, Mg, Na and K) and several trace metals (Fe, Mn, Li, Sr, Ba, B, Cr, Zn, Ni, Pb, Cu, Co, Cd, As and Se). The ICP is an optically thin emission source formed by coupling radiofrequency power into a stream of argon gas. The argon is constrained into three concentric streams in a plasma torch fabricated from fused silica. A toroidal shaped plasma is formed, and the sample is injected through the central tunnel, heated to a high temperature (8000 K) and thereby atomized to a large extent. Emission from the excited atoms and ions is observed at a height of 10 to 20 mm above the load coil by a conventional spectrometer system.

4.1.2 Ion Chromotography

Ion Chromotograph, model Dionex 2020i was used for the analysis of the anions: Cl^-, F^-, NO_3^-, SO_4^{2-} and PO_4^{2-}. The Dionex-2020i ion chromatograph is a dual channel, high-performance chromatographic system featuring two precision analytical pumps, a dual channel advanced chromatography module with optional column heater and two conductivity detectors. The modular design of the system makes it easy to tailor the system to individual analytical needs. The components are housed in three sturdy, corrosion-resistant enclosures. The operating conditions were 10 to 40 °C temperature range and 1900 psi (129 atm) maximum pressure.

4.1.3 Atomic Absorption Spectrophotometry (AAS)

This technique was used for the analysis of some major ions (Ca, Mg, Na and K) and several trace metals (Fe, Li, Sr, Ba, B, Cr, Zn, Ni, Pb, Cu, Co, Cd, Mn, As and Se). For determination of total metals in water, the water sample is acidified with nitric acid (8 ml/l) and boiled for 4-5 minutes and then filtered, if necessary. Simultaneously a blank, preferably in duplicate with deionized water having the same amount of nitric acid should be run in identical conditions. This blank, to some extent, takes care of the errors due to reagents and/or environment. The

contamination of iron, chromium, copper, nickel and zinc from different equipment of the laboratory is very common. The samples then spirated to double beam Atomic Absorption Spectrometer (GBC 906) equipped with autosampler and direct background corrector.

4.2 Field-Measured Parameters

Because their values change with time, the Total Dissolved Solids (TDS) contents in milligrams per liter (mg/l) and hydrogen-ion concentration (pH) of collected water samples were directly measured in the field. The following is a brief discussion on each of these parameters:

4.2.1 Total Dissolved Solids

The total dissolved solids in a water sample includes all solid materials in solution whether ionized or not. It does not include suspended sediments, colloids or dissolved gases. The TDS content in groundwater is an indication of its salinity. A simple classification of groundwater salinity depending on the total concentration of dissolved constituents, as proposed by Todd (1980), is given in Table (3).

The TDS content in groundwater samples collected in February 1995 ranged from 424 mg/l on Al Jaww plain (Well no. 69) to 10,325 mg/l northwest of Al Oha area (Well no. 20). In March 1996, the TDS content

of water samples ranged from 525 mg/l north of Wadi Masakin and east of Al Ain - Dubai road (Well no. 3) to 6,144 mg/l north of Al Hili and south of Al Oha area (Well no. 13).

Table 3. Classification of groundwater according to its TDS content in mg/l (Todd, 1980).

Water type	Total Dissolved Solids (mg/l)
Fresh water	0 - 1,000
Brackish water	1,000 - 10,000
Saline water	10,000 - 100,000
Brine	> 100,000

The 1995 and 1996 iso-salinity contour maps of the Quaternary aquifer in the Al Ain and Al Oha areas show that the groundwater salinity increases from east to west; in the direction of groundwater flow. The effect of more than one inferred alluvial channel is reflected in the configuration of the isosalinity contours. However, the most conspicuous channel runs in a NE-SW direction, causing the presence of a relatively fresh groundwater tongue between Al Hayer and Al Saad areas (Figure 9).

The TDS contents in the Quaternary aquifer of Al Ain area in February 1995 exceeded the WHO (1971) recommended limits for drinking water, especially of the wells located in the western part of the study area (Figure 10).

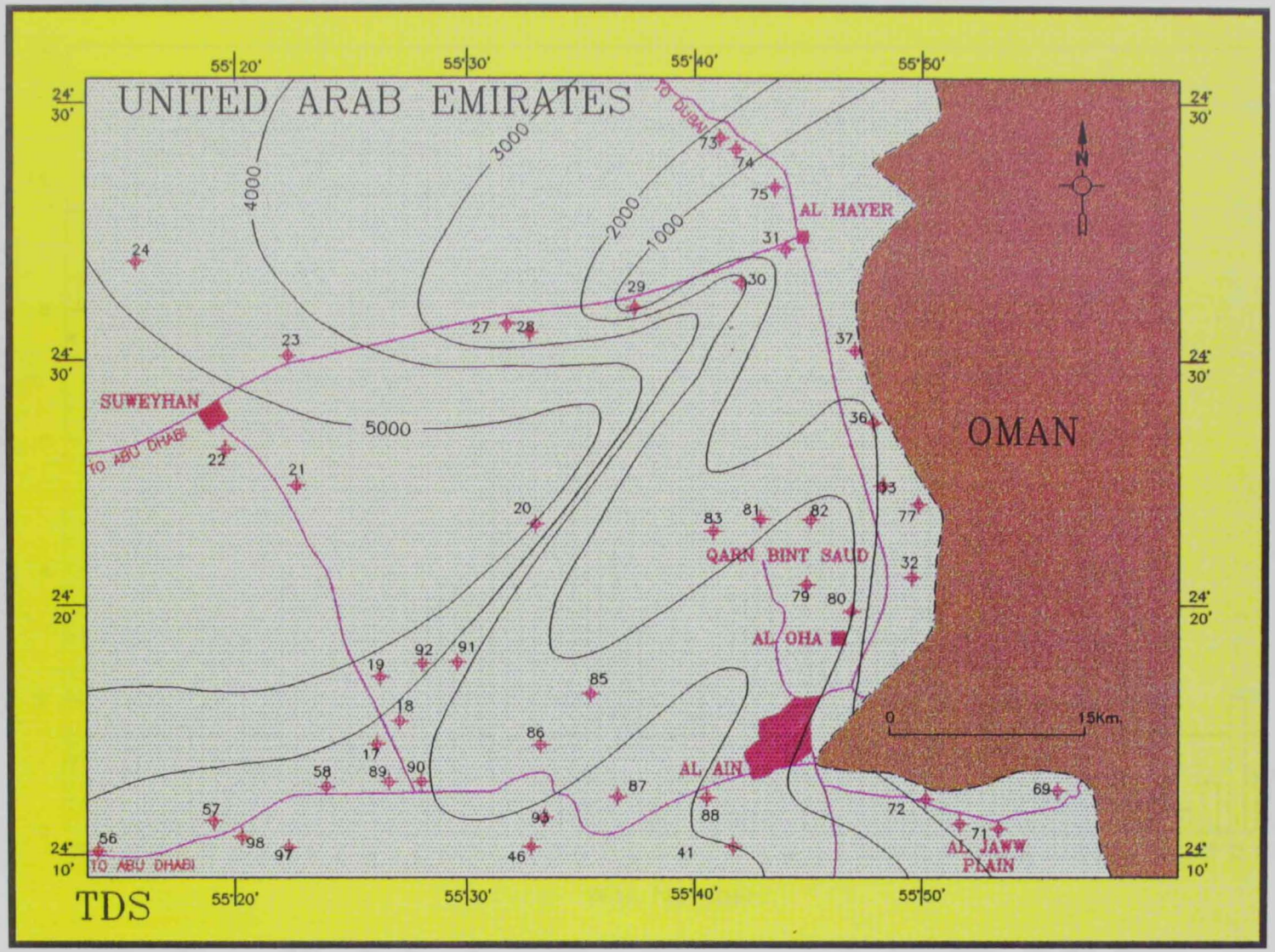

Figure 9. Iso-salinity contour map, mg/l, of groundwater in the Quaternary aquifer at Al Ain area in February 1995.

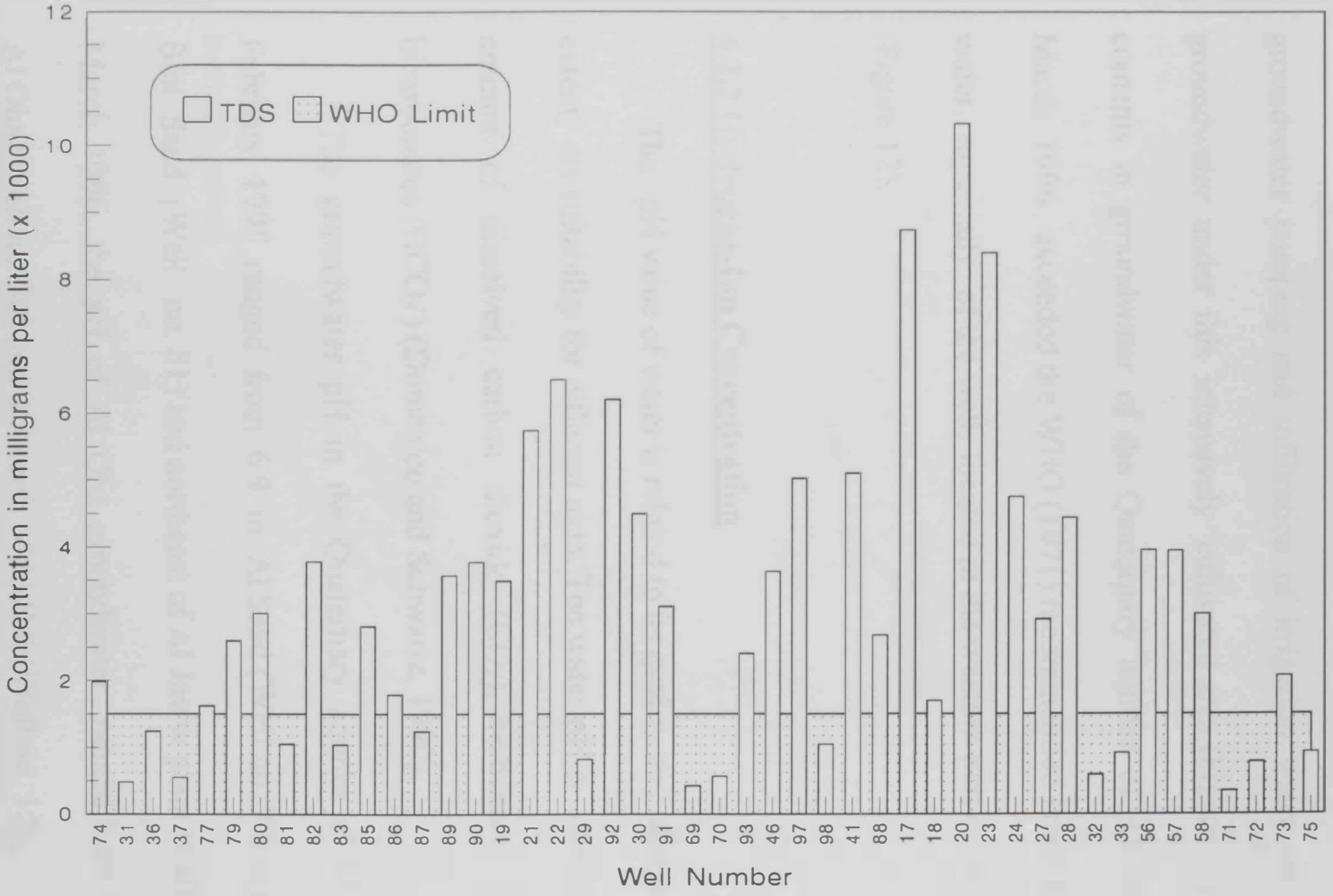

Figure 10. A bar graph illustrating the TDS contents in Al Ain groundwater compared with the WHO (1971) recommended limits for drinking water, February 1995.

The 1996 iso-salinity contour map indicates the presence of a relatively high-salinity water east of Al Oha area. This reflects the effect of groundwater pumping and infiltration of irrigation water on salinity of groundwater under this intensively cultivated area (Figure 11). The TDS contents in groundwater of the Quaternary aquifer of Al Oha area in March 1996 exceeded the WHO (1971) recommended limits for drinking water, especially of the wells located in the western part of the study area (Figure 12).

4.2.2 Hydrogen-Ion Concentration

The pH value of water is related to its quality and affects, to a great extent, its suitability for different uses. The water pH is controlled by the amount of dissolved carbon dioxide (CO_2), carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) (Domenico and Schwartz, 1990).

The groundwater pH in the Quaternary aquifer of Al Ain area in February 1995 ranged from 6.9 in Al Saad (Well no. 90) to 8.2 in Qarn Bint Saud (Well no. 81) and northeast of Al Jaww plain (well no. 69). In March 1996, the pH of Al Oha groundwater ranged from 7.6 north of Al Oha (Well no. 30) and 8.5 north of Al Hili (Well no. 15).

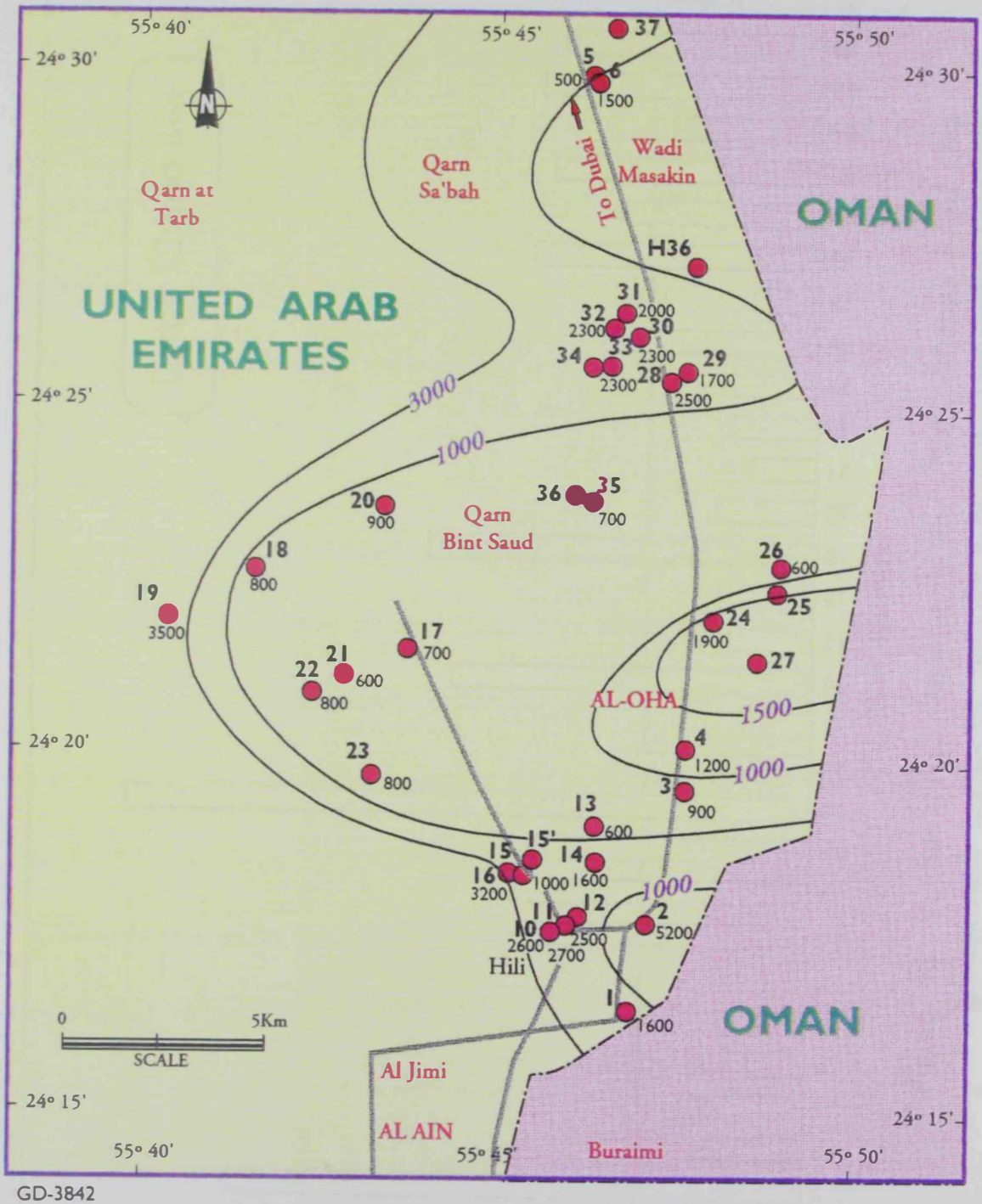

Figure 11. Iso-salinity contour map, mg/l, of groundwater in the Quaternary aquifer at Al Oha area in March 1996.

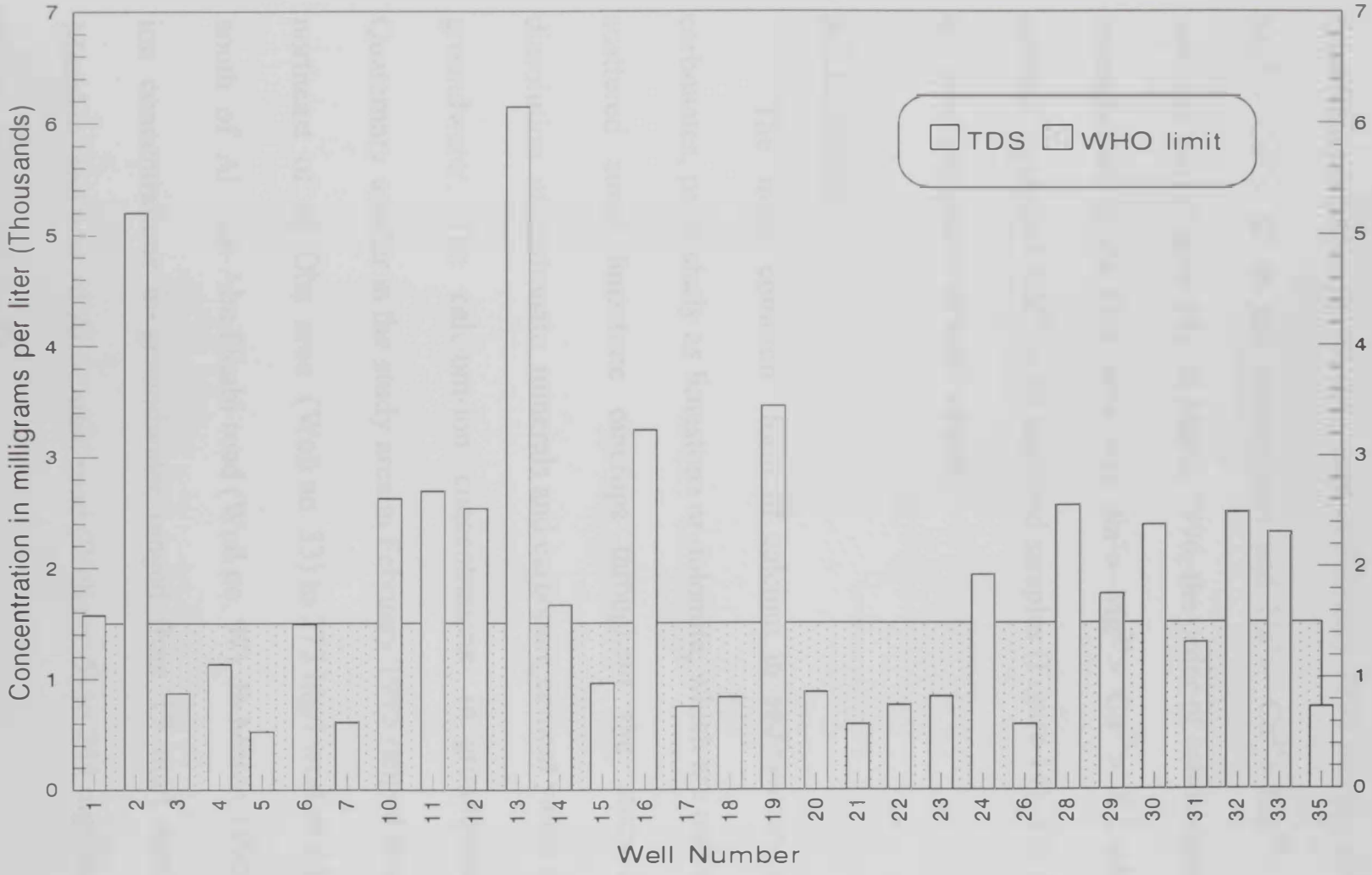

Figure 12. A bar graph illustrating the TDS contents in Al Oha groundwater compared with the WHO (1971) recommended limits for drinking water, March 1996.

4.3 Major Cations

The sequence of cation dominance in groundwater of the Quaternary aquifer in Al Ain area in February 1995 has the order: $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ in the eastern part and $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ in the western part (Figure 13). In March 1996, the order of cation dominance in groundwater of Al Oha area was $Na^+ > Mg^{2+} > Ca^{2+} > K^+$, where Mg^{2+} content exceeded Ca^{2+} in all analyzed samples (Figure 14). The following is a brief discussion on each cation:

4.3.1 Calcium

The most common form of calcium in sedimentary rocks are carbonates, particularly as limestone or dolomite, which are represented by scattered small limestone outcrops throughout the study area. The dissolution of carbonate minerals and carbonate cement yields calcium to groundwater. The calcium-ion concentrations in groundwater of the Quaternary aquifer in the study area in February 1995 ranged from 16 mg/l northeast of Al Oha area (Well no. 33) to 275 mg/l west of Al Saad and south of Al Ain-Abu Dhabi road (Well no. 97). In March 1996, calcium-ion concentrations in groundwater ranged from 19 mg/l north of Wadi Masakin and east Al Ain-Dubai road (Well no. 5) to 244 mg/l northeast of Al Hili area (Well no. 2).

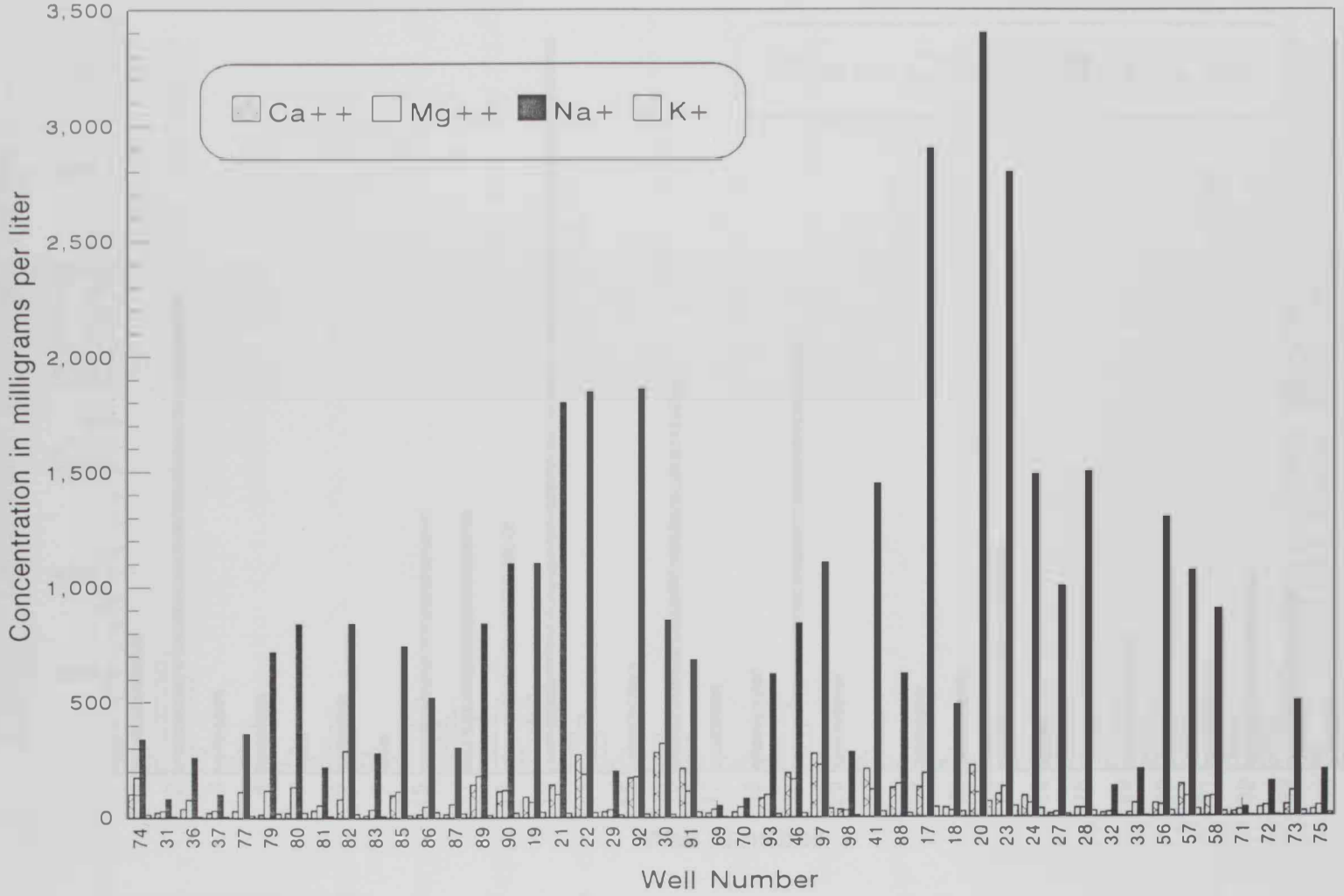

Figure 13. A bar graph showing the cation domniance in Al Ain groundwater, February 1995.

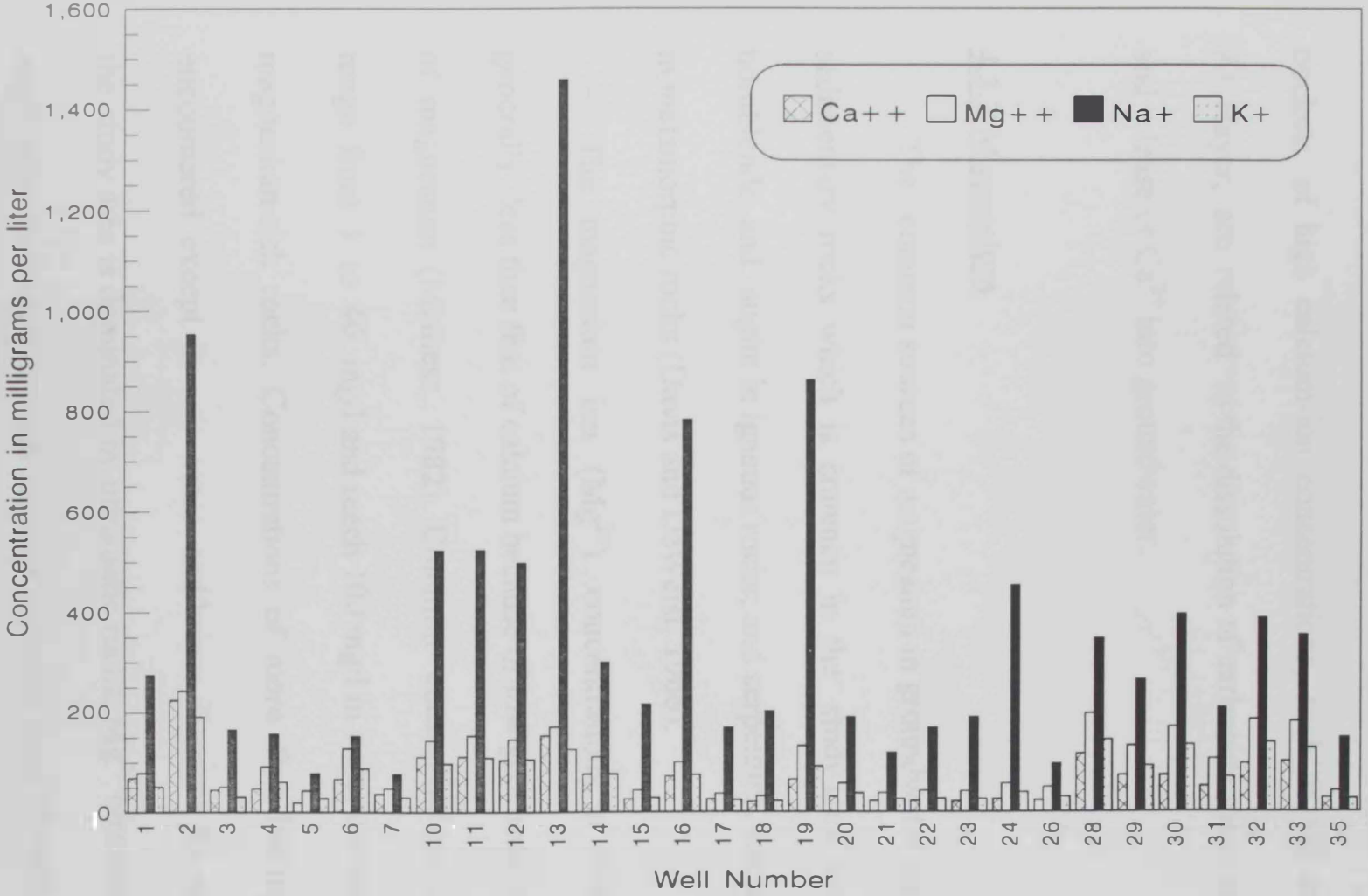

Figure 14. A bar graph showing the cations domniance in Al Oha groundwater, March 1996.

The 1995 and 1996 iso-concentration contour maps show a gradual increase in calcium ion from east to west (Figures 15 and 16). Local pockets of high calcium-ion concentrations, such as the area west of Al Hayer, are related to the dissolution of carbonate rocks in these areas and release of Ca^{2+} into groundwater.

4.3.2 Magnesium

The common sources of magnesium in groundwater are dolomite in sedimentary rocks which is common in the study area; olivine, biotite, hornblende and augite in igneous rocks; and serpentine, talc and tremolite in metamorphic rocks (Davis and DeWeist, 1966).

The magnesium ion (Mg^{2+}) concentrations in fresh water are generally less than that of calcium because of low geochemical abundance of magnesium (Mathess, 1982). Common concentrations of magnesium range from 1 to 40 mg/l and reach 100 mg/l in water circulating through magnesium-rich rocks. Concentrations of more than 100 mg/l are rarely encountered except in sea water and brines. Because the eastern part of the study area is dominated by ultramafic rocks, Mg^{2+} concentrations >100 mg/l were measured in water samples collected from 20 wells in February 1995, and in water samples collected from 15 wells in March 1996.

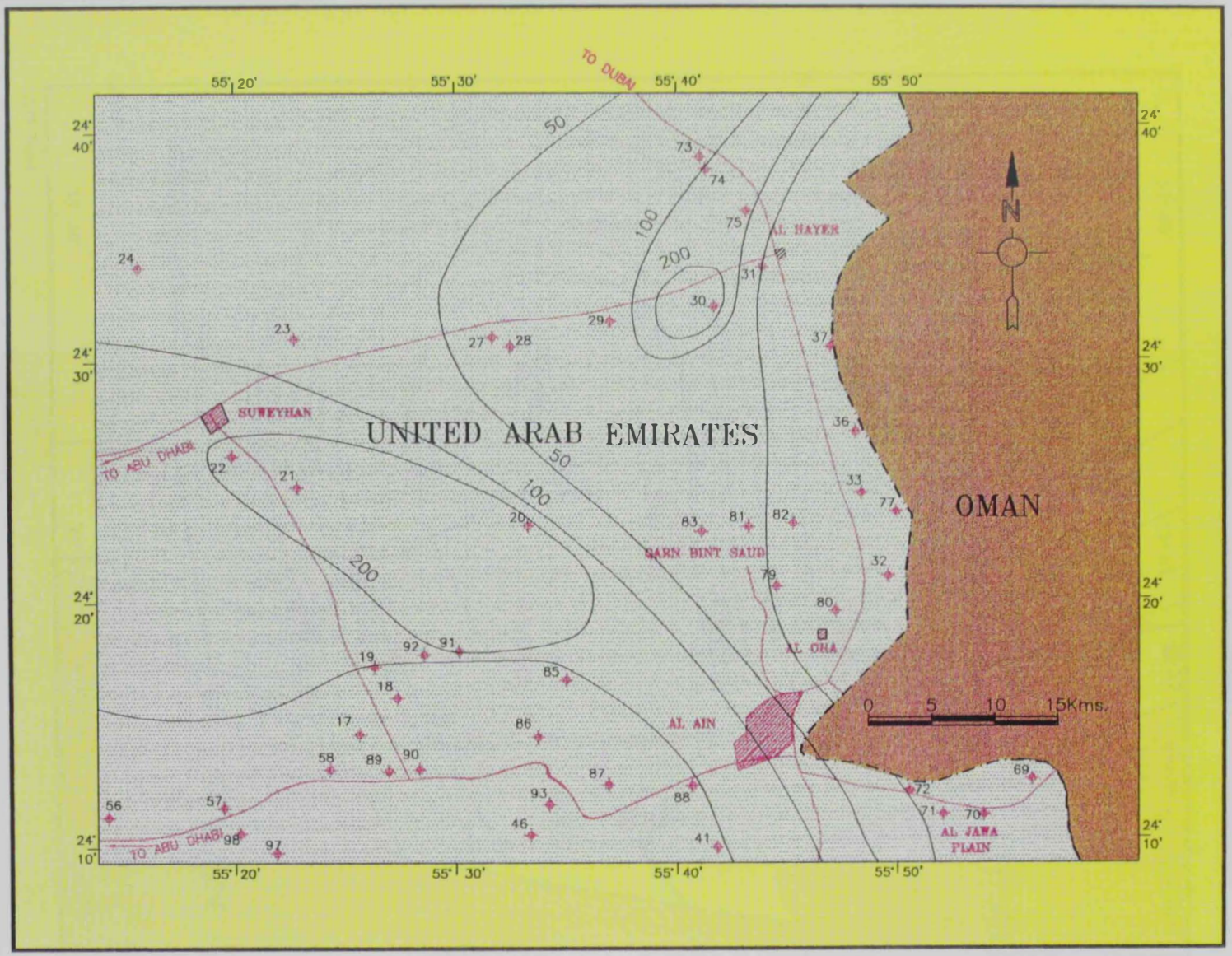

Figure 15. Iso-concentration contour map, mg/l, of the calcium ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

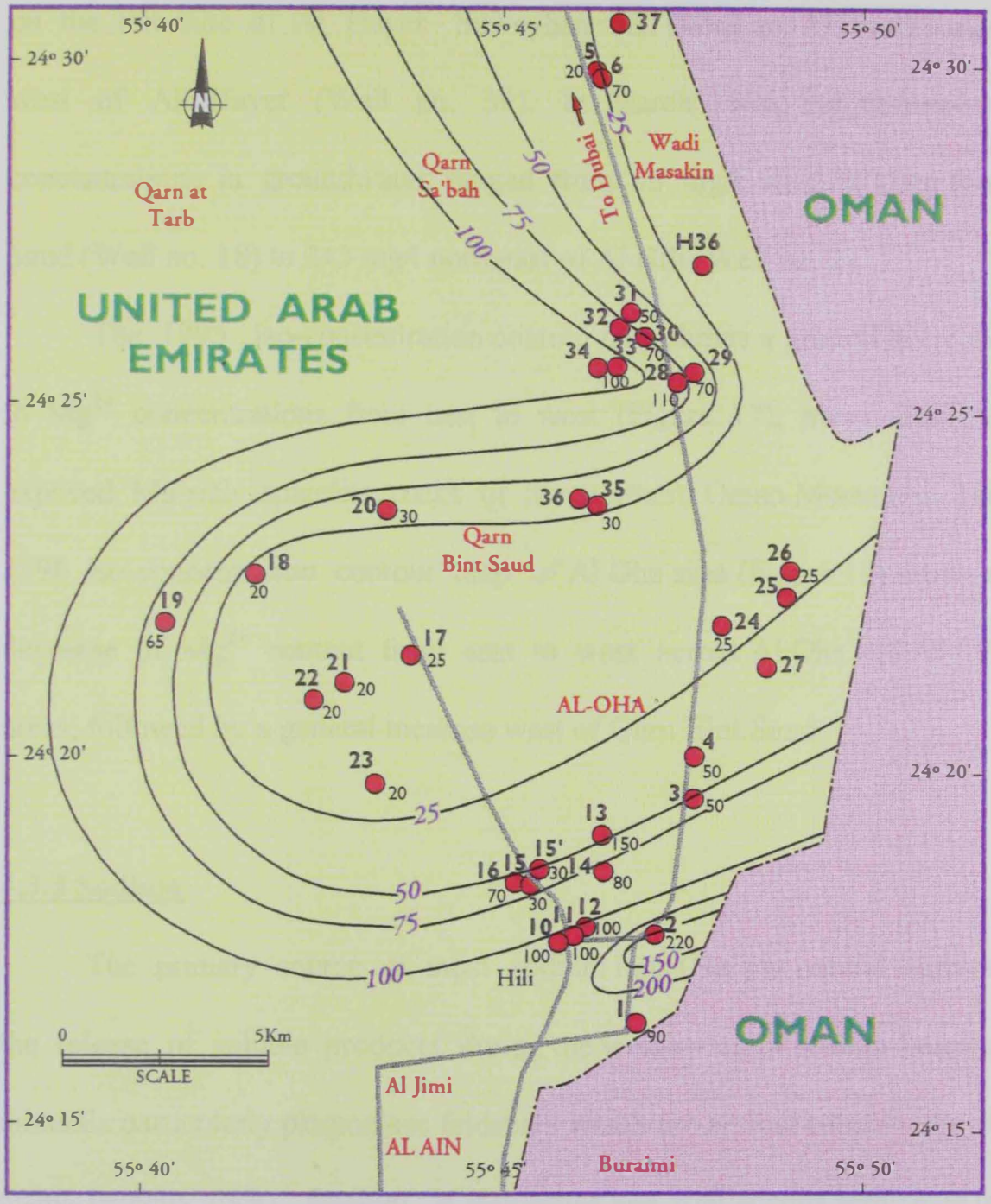

Figure 16. Iso-concentration contour map, mg/l, of the calcium ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

Magnesium-ion (Mg^{2+}) concentration in groundwater of the Quaternary aquifer in the study area in February 1995 ranged from 20 mg/l on the left side of Al Hayer - Suweyhan road (Well no. 27) to 321 mg/l west of Al Hayer (Well no. 30). In March 1996, magnesium-ion concentrations in groundwater ranged from 33 mg/l west of Qarn Bint Saud (Well no. 18) to 243 mg/l northeast of Al Hili (Well no. 2).

The 1995 iso-concentration contour map shows a general decrease in Mg^{2+} concentrations from east to west (Figure 17), away from the exposed Mg-rich ophiolite rocks of the northern Oman Mountains. The 1996 iso-concentration contour map of Al Oha area (Figure 18) shows a decrease of Mg^{2+} content from east to west across Al Oha and Al Hili areas, followed by a general increase west of Qarn Bint Saud.

4.3.3 Sodium

The primary source of most sodium ions (Na^{+}) in natural water is the release of soluble products during the weathering of sodium-bearing minerals particularly plagioclase feldspars which are typical constituents of many igneous rocks. Sodium in evaporites and argillaceous sediments is more likely to be the main source of Na^{+} in groundwater within the study area.

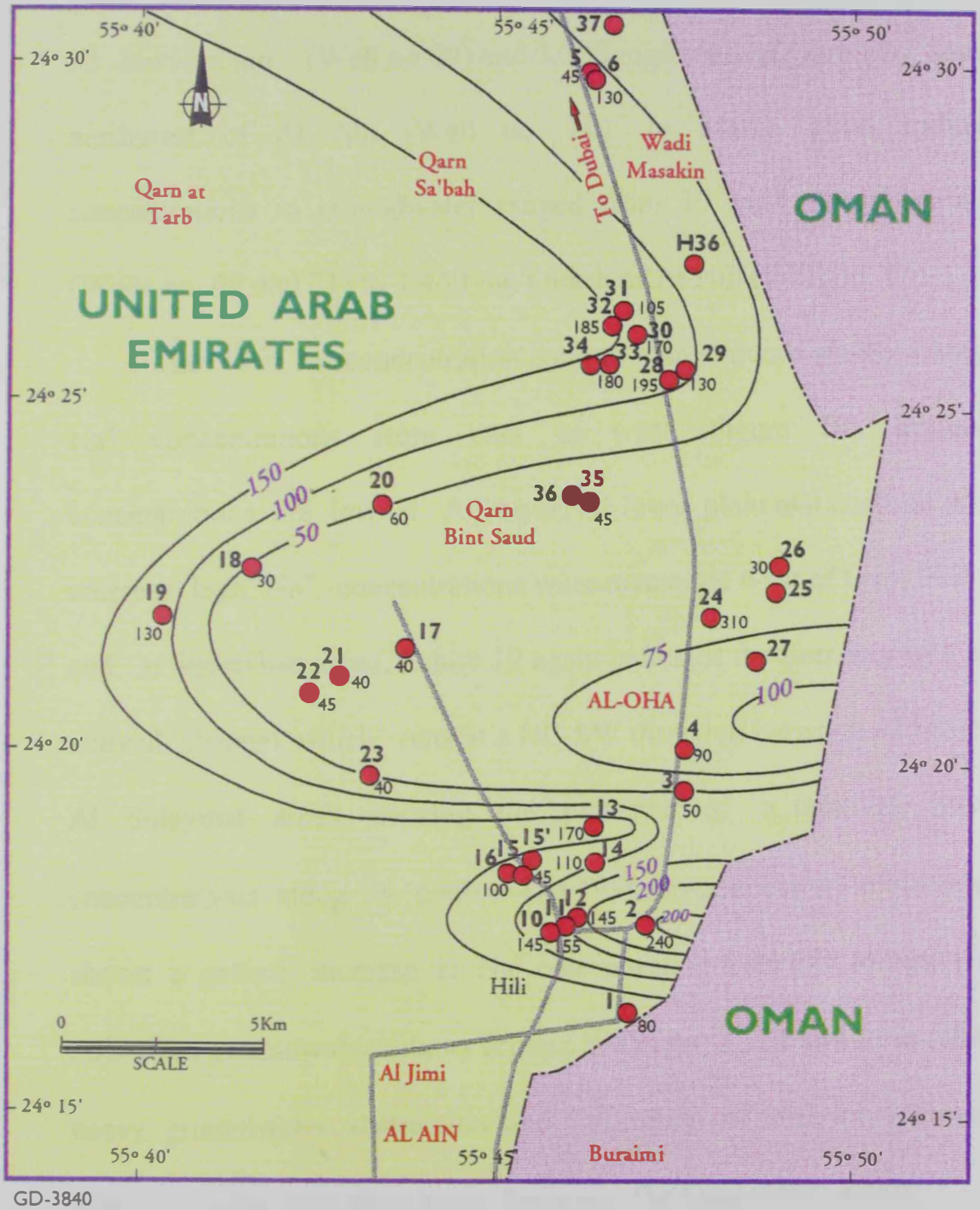

Figure 18. Iso-concentration contour map, mg/l, of the magnesium ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

Sodium-ion concentrations in groundwater of the Quaternary aquifer in the study area in February 1995 ranged from 18 mg/l in the northeast of Al Jaww plain (Well no.69) and 3,398 mg/l west of Qarn Bint Saud and northwest of Al Ain (Well no. 20). In March 1996, sodium-ion concentrations in groundwater ranged from 39 mg/l on Al Jaww plain (Wells no. 69 and 71) to 1,460 mg/l north of Al Hili (Well no. 13).

The 1995 iso-concentration contour map shows a steady increase in Na^+ concentrations from east to west (Figure 19). Sodium-ion concentrations are low at Al Hayer, Al Jaww plain and north of Al Oha, whereas high Na^+ concentrations were measured west of Qarn Bint Saud and at Suweyhan areas. Figure 19 again indicates the presence of a buried alluvial channel which runs in a NE-SW direction between Al Hayer and Al Sulaymat areas, causing the presence of a relatively low Na^+ concentrations along its course. The 1996 iso-concentration contour map shows a general increase in Na^+ concentration from east to west (Figure 20). High groundwater salinity around Wells no. 2, 24 and 27 is related to heavy groundwater abstraction and infiltration of relatively high-salinity irrigation water from farm lands down into the Quaternary aquifer.

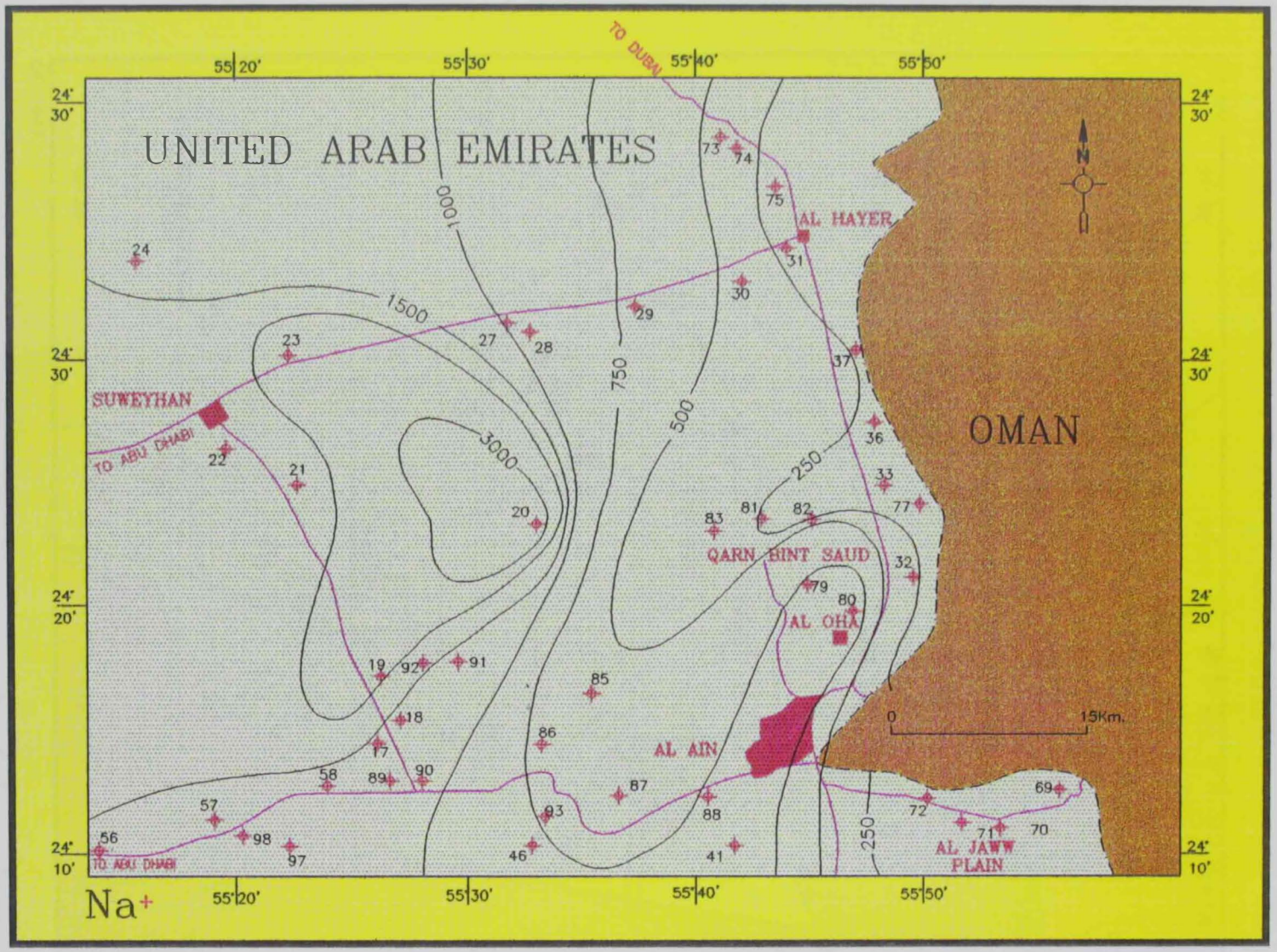

Figure 19. Iso-concentration contour map, mg/l, of the sodium ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

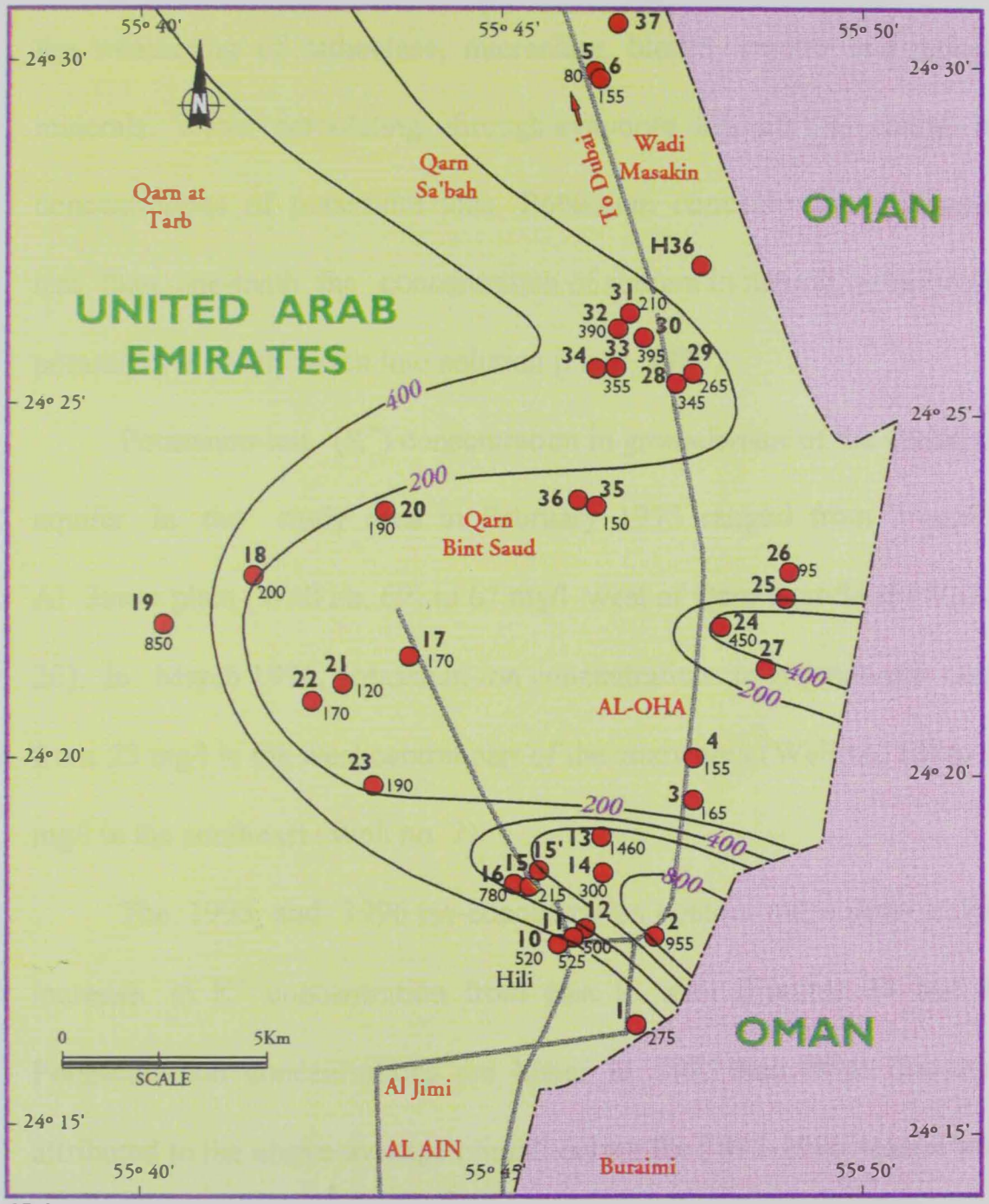

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Figure 20. Iso-concentration contour map, mg/l, of the sodium ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

4.3.4 Potassium

The most common source of potassium ions (K^+) in groundwater is the weathering of orthoclase, microcline, biotite, leucite and nepheline minerals. Water percolating through evaporite deposits may contain high concentrations of potassium ions. Potassium concentration is commonly less than one-tenth the concentration of sodium in natural water because potassium is hardly taken into solution (Hem, 1970).

Potassium-ion (K^+) concentration in groundwater of the Quaternary aquifer in the study area in February 1995 ranged from 2 mg/l on Al Jawv plain (Well no. 69) to 67 mg/l west of Qarn Bint Saud (Well no. 20). In March 1996, potassium-ion concentrations in groundwater ranged from 23 mg/l in the west central part of the study area (Well no. 18) to 199 mg/l in the southeast (Well no. 2).

The 1995 and 1996 iso-concentration contour maps show a steady increase in K^+ concentration from east to west (Figurse 21 and 22). Potassium ion concentrations are lower in 1995 than 1996. This can be attributed to the above-average rainfall during the 1995-1996 season which have leached high K^+ concentrations from farm lands into groundwater under cultivated areas.

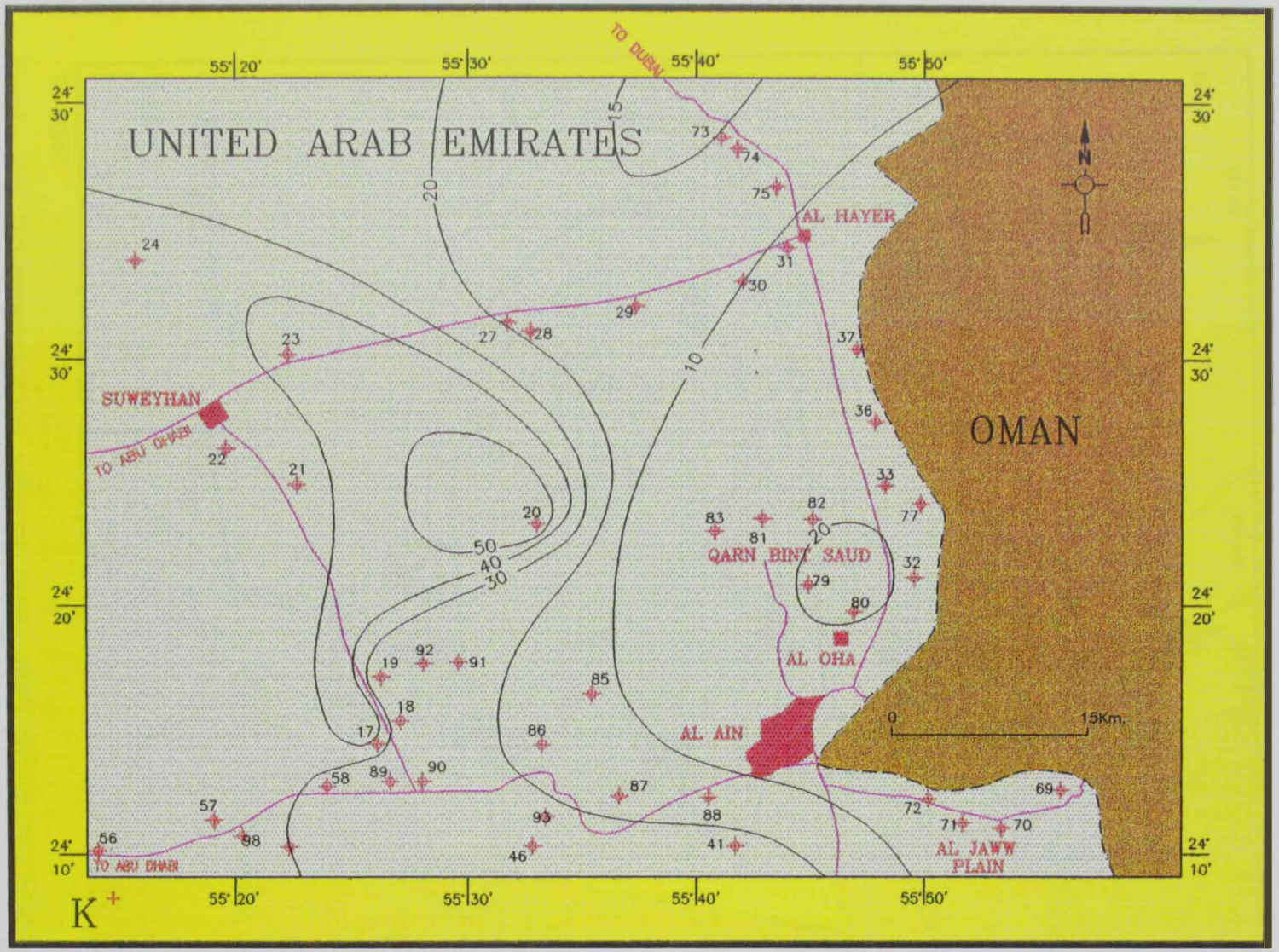

Figure 21. Iso-concentration contour map, mg/l, of the potassium ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

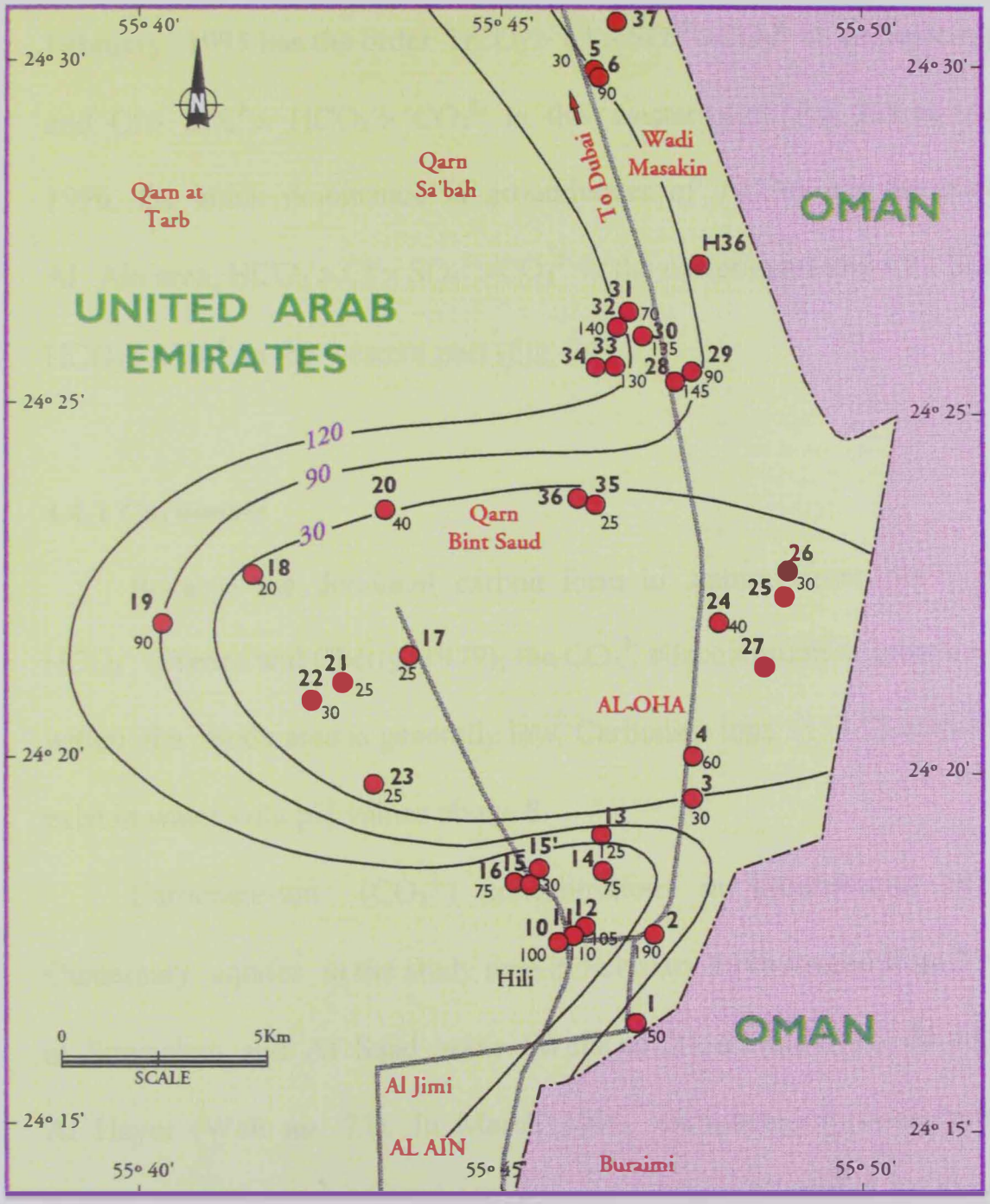

Figure 22. Iso-concentration contour map, mg/l, of the potassium ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

4.4 Major Anions

The sequence of anion dominance in groundwater of Al Ain area in February 1995 has the order: HCO_3^-> Cl^-> SO_4^{2-}>CO_3^{2-} in the eastern part and Cl^-> SO_4^{2-}> HCO_3^-> CO_3^{2-} in the western part (Fig. 23). In March 1996, the anion dominance in groundwater of Al Oha was the same as Al Ain area; HCO_3^-> Cl^-> SO_4^{2-}>CO_3^{2-} in the eastern part and Cl^-> SO_4^{2-}> HCO_3^-> CO_3^{2-} in the western part (Fig. 24).

4.4.1 Carbonate

Because the dominant carbon form in natural water (pH 6 - 8) is HCO_3^- (Freeze and Cherry, 1979), the CO_3^{2-} concentration in groundwater within the study area is generally low. Carbonate ions (CO_3^{2-}) commonly exist in water with pH values above 8.

Carbonate-ion (CO_3^{2-}) concentrations in groundwater of the Quaternary aquifer in the study area in February 1995 ranged from 3 mg/l at Suweyhan and Al Saad areas (Wells no. 21, 22 and 89) to 24 mg/l at Al Hayer (Well no. 75). In March 1996, carbonate-ion concentrations ranged from 5 mg/l in the northeastern part of the study (Well no. 6) to 39 mg/l in the west central part of the study area (Well no. 19).

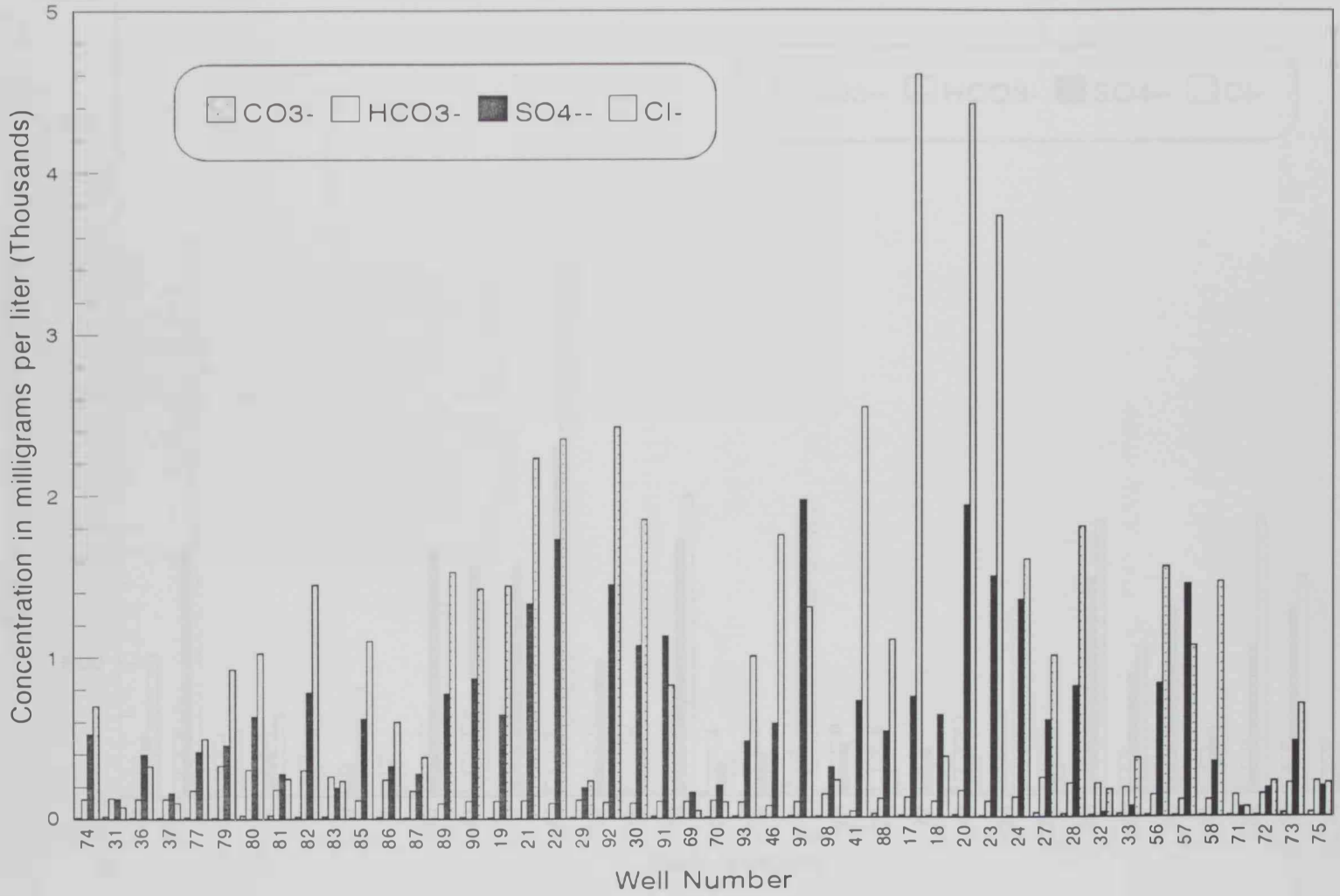

Figure 23. A bar graph showing the anion domniance in Al Ain groundwater, February 1995.

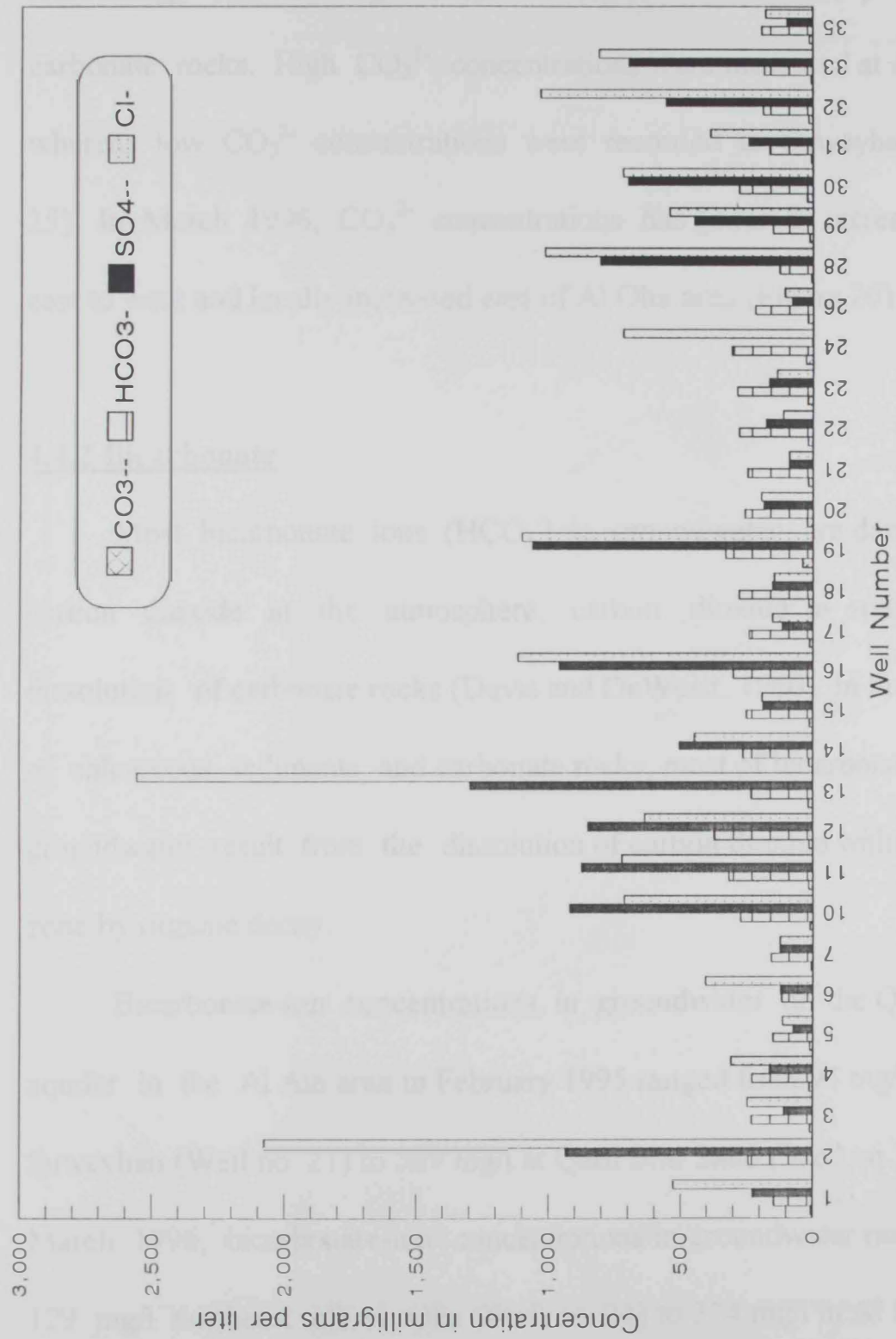

Figure 24. A bar graph showing the anion dominance in Al Oha groundwater, March 1996.

In 1995, the iso-concentration contour map shows a close relationship between high CO_3^{2-} concentrations and the presence of carbonate rocks. High CO_3^{2-} concentrations were measured at Al Hayer, whereas low CO_3^{2-} concentrations were recorded at Suweyhan (Figure 25). In March 1996, CO_3^{2-} concentrations has generally increased from east to west and locally increased east of Al Oha area (Figure 26).

4.4.2 Bicarbonate

Most bicarbonate ions (HCO_3^-) in groundwater are derived from carbon dioxide in the atmosphere, carbon dioxide in soils and by dissolution of carbonate rocks (Davis and DeWeist, 1966). In the absence of calcareous sediments and carbonate rocks, most of bicarbonate ions in groundwater result from the dissolution of carbon dioxide within the soil zone by organic decay.

Bicarbonate-ion concentrations in groundwater of the Quaternary aquifer in the Al Ain area in February 1995 ranged from 95 mg/l south of Suweyhan (Well no. 21) to 329 mg/l at Qarn Bint Saud (Well no. 79). In March 1996, bicarbonate-ion concentrations in groundwater ranged from 129 mg/l northeast of Al Oha (Well no. 24) to 374 mg/l in Al Hili (Well no. 12).

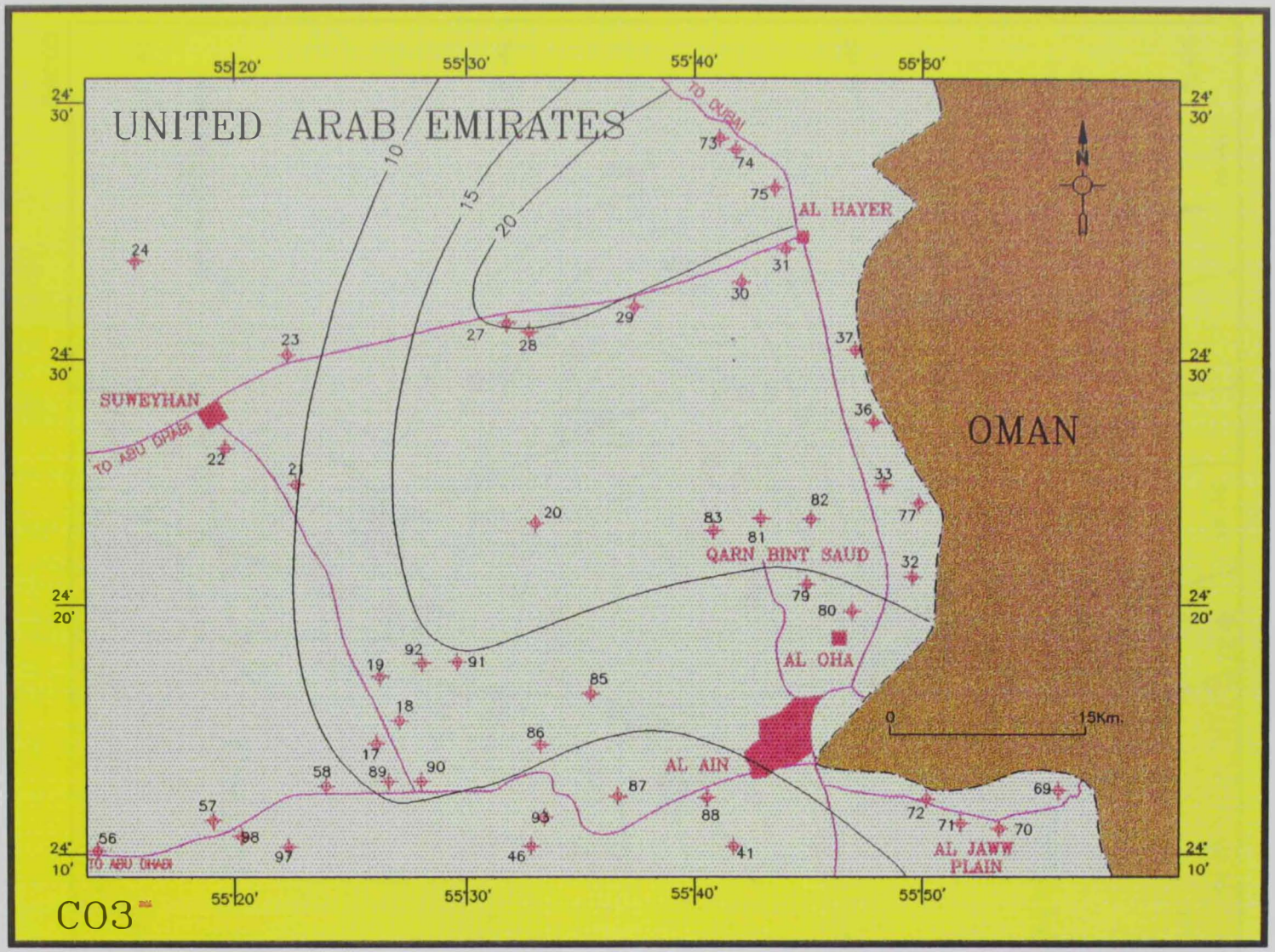

Figure 25. Iso-concentration contour map, mg/l, of the carbonate ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

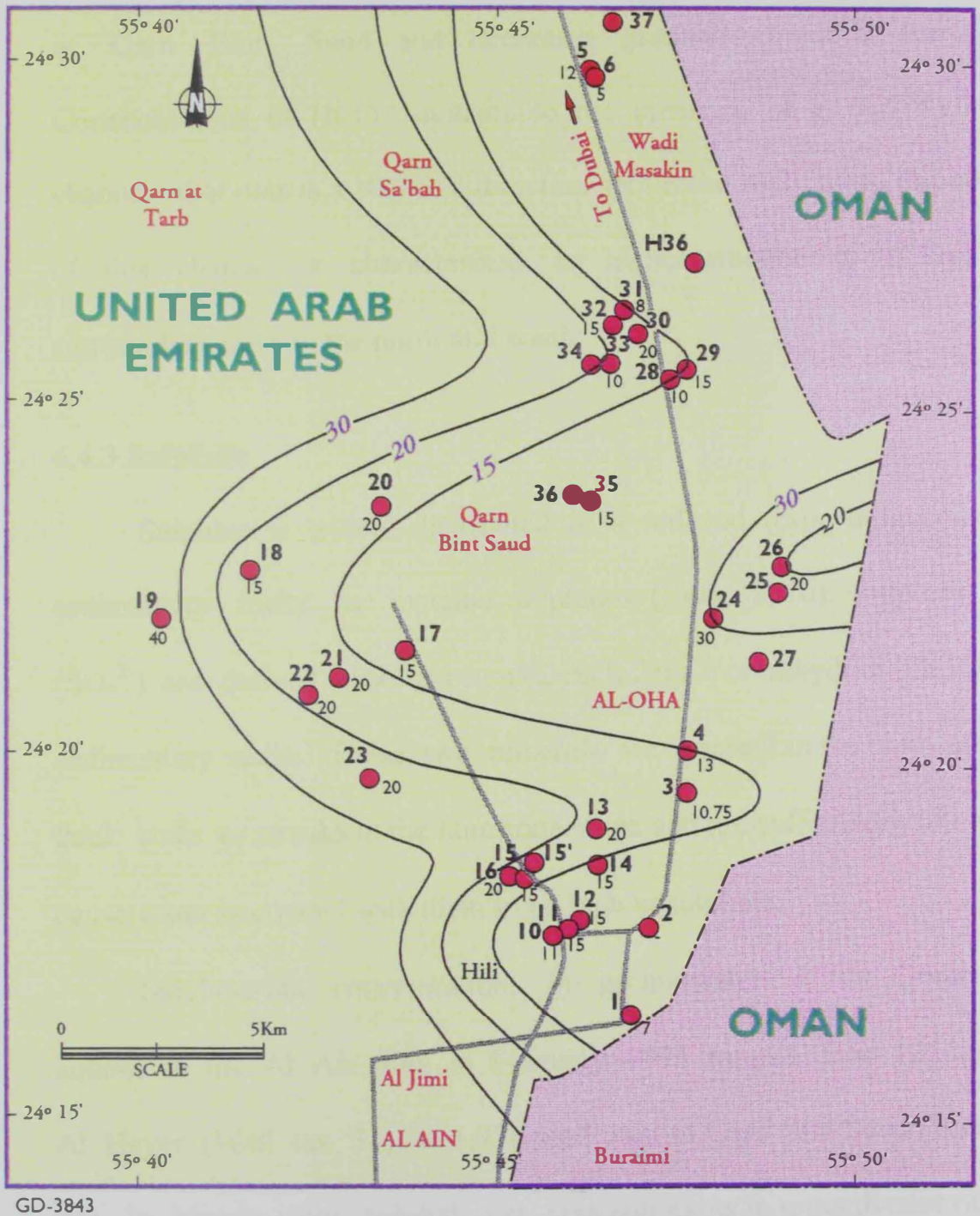

Figure 26. Iso-concentration contour map, mg/l, of the carbonate ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

The 1995 and 1996 iso-concentration contour maps show a steady decrease in HCO_3^- concentrations from east to west, in the direction of groundwater flow (Figures 27 and 28). Bicarbonate-ion contents are high at Qarn Bint Saud and decreases gradually towards the west. Concentrations of HCO_3^- indicate to the presence of a buried alluvial channel that runs in a NE- SW direction across the study area. The course of this channel is characterized by higher amounts of HCO_3^- than surrounding areas in the north and south.

4.4.3 Sulphate

Sulphate is widely distributed in a reduced form in igneous and sedimentary rocks as metallic sulphides (Hem, 1970). Sulphate ions (SO_4^{2-}) are derived from gypsum ($CaSO_4.2H_2O$) or anhydrite ($CaSO_4$) in sedimentary rocks. These two minerals are present in the study area as thick beds or streaks in the limestone strata and are sufficiently soluble to cause water in contact with them to be high in sulphate.

Sulphate-ion concentrations in groundwater of the Quaternary aquifer in the Al Ain area in February 1995 ranged from 125 mg/l at Al Hayer (Well no. 31) to 1,936 mg/l west of Qarn Bint Saud (Well no. 20). In March 1996, sulphate-ion concentrations in groundwater ranged from 76 mg/l north of Wadi Masakin (Well no. 5) to 1,296 mg/l at Al Hili (Well no. 3).

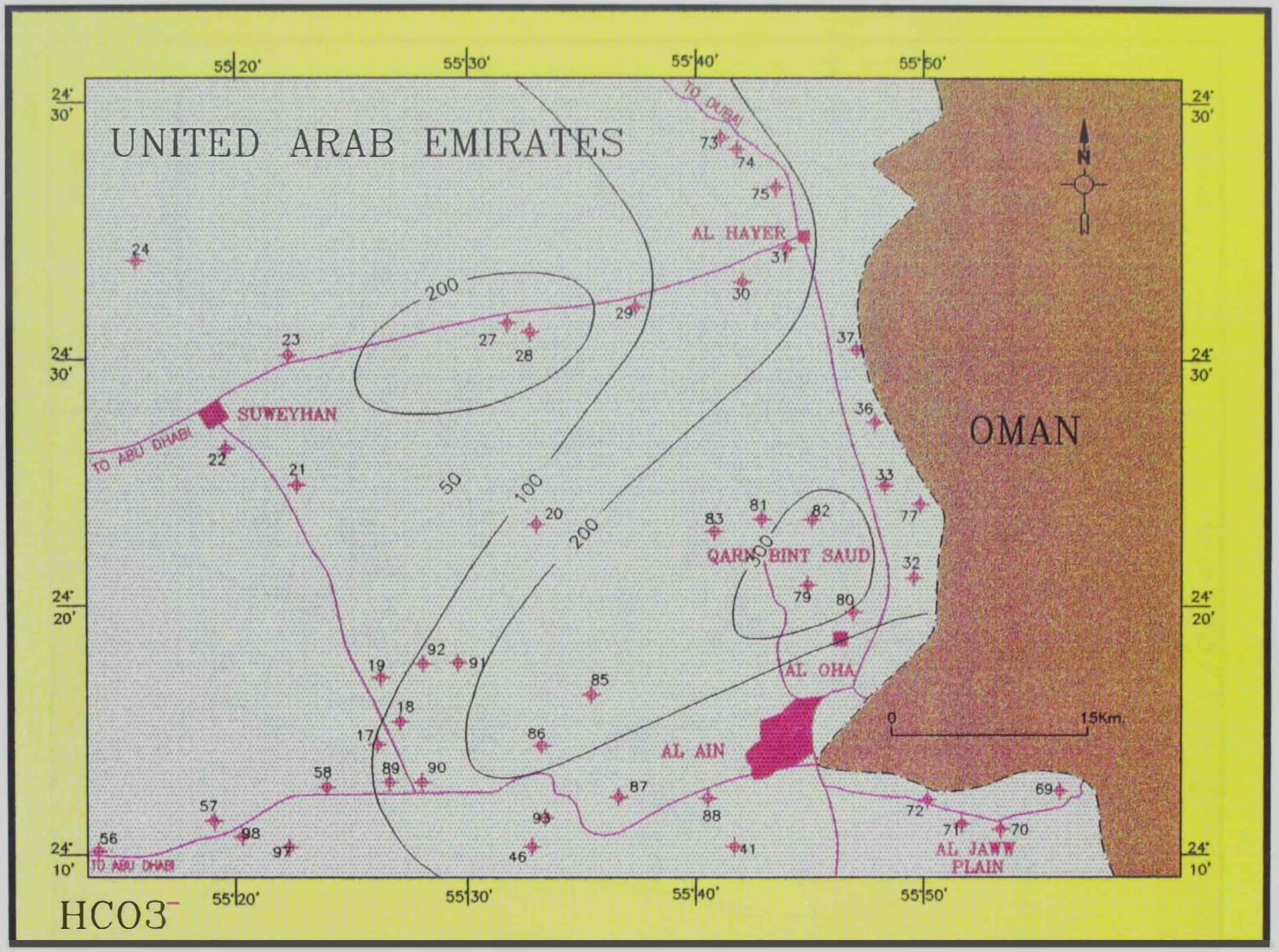

Figure 27. Iso-concentration contour map, mg/l, of the bicarbonate ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

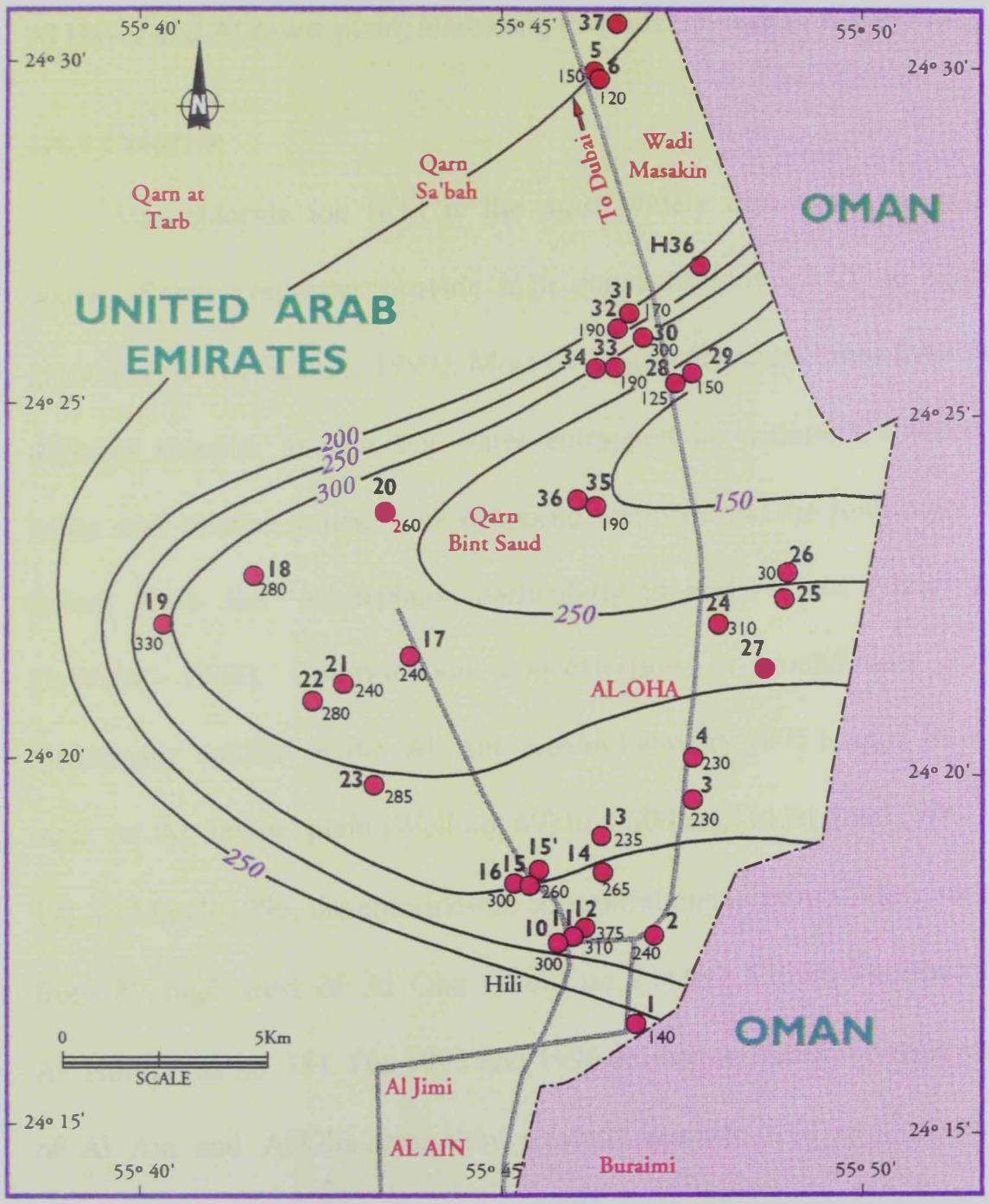

Figure 28. Iso-concentration contour map, mg/l, of the bicarbonate ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

The 1995 and 1996 iso-concentration contour maps of Al Ain and Al Oha areas show a steady increase in SO_4^{2-} concentrations from east to west (Figures 29 and 30). Sulphate-ion concentrations are low at Al Hayer and Al Jaww plain, increasing towards Suweyhan in the west.

4.4.4 Chloride

The chloride ion (Cl^-) is the most widely distributed in natural water. Some evaporites provide high concentrations of Cl^- to normal groundwater (El-Shami, 1990). Most Cl^- in groundwater comes from four different sources; ancient sea water entrapped in sediment, solution of halite and related minerals in evaporite deposits and the solution of dry fallout from the atmosphere, particularly in arid regions (Davis and DeWeist, 1966). Chloride ion concentrations in groundwater of the Quaternary aquifer in the Al Ain area in February 1995 ranged from 46 mg/l on Al Jaww plain (Well no. 69) to 4,600 mg/l at Al Saad (Well no. 17). In March 1996, the chloride-ion concentrations in groundwater ranged from 89 mg/l west of Al Oha (Well no. 21) to 2,556 mg/l northeast of Al Hili (Well no. 13). The 1995 and 1996 iso-concentration contour maps of Al Ain and Al Oha areas show a steady increase in Cl^- concentrations from east to west (Figures 31 and 32). Chloride-ion concentrations are low on Al Jaww plain (70 mg/l), Qarn Bint Saud (89 mg/l) and Al Hayer (99 mg/l), increasing gradually towards Suweyhan in the west.

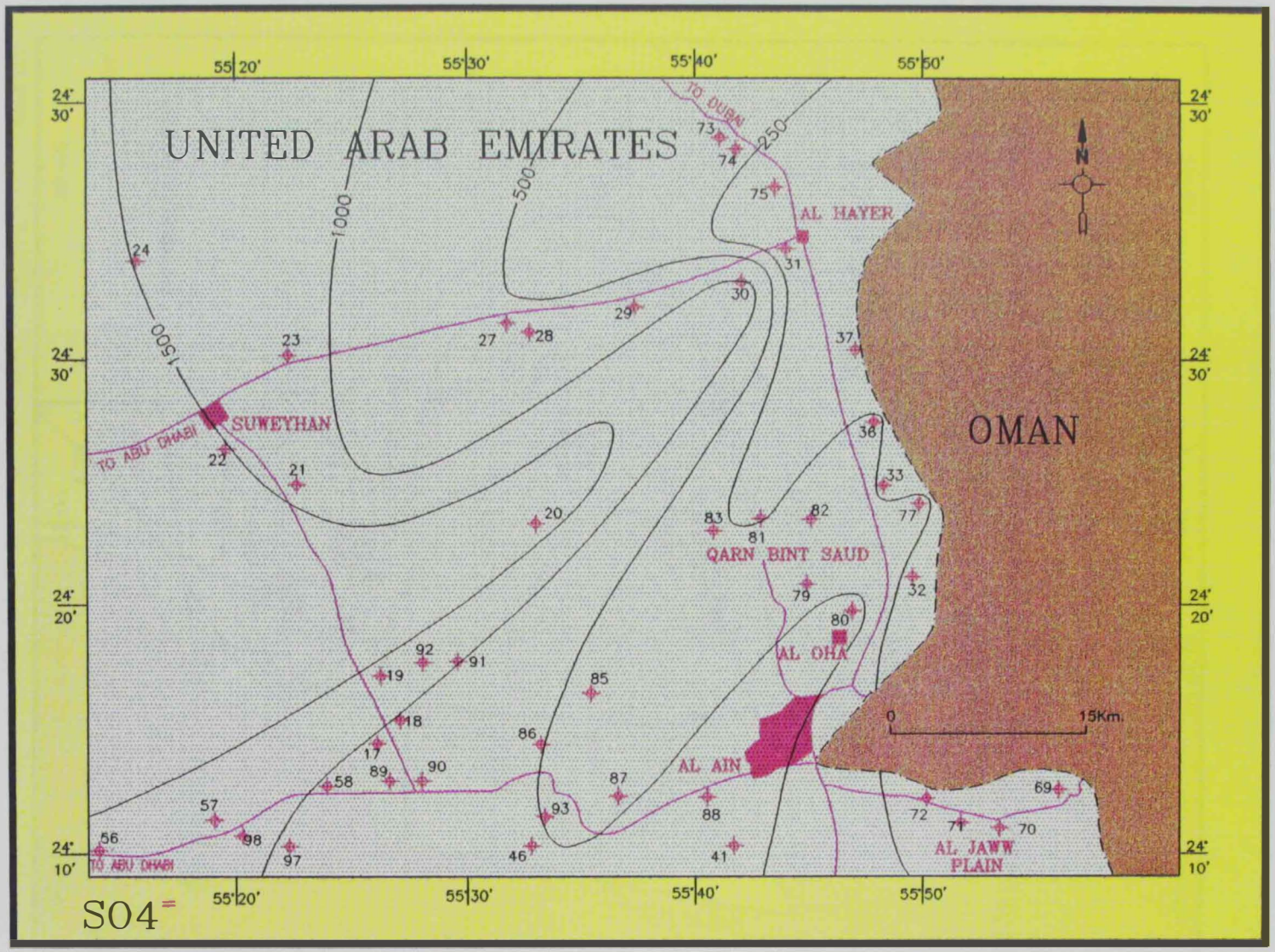

Figure 29. Iso-concentration contour map, mg/l, of the sulphate ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

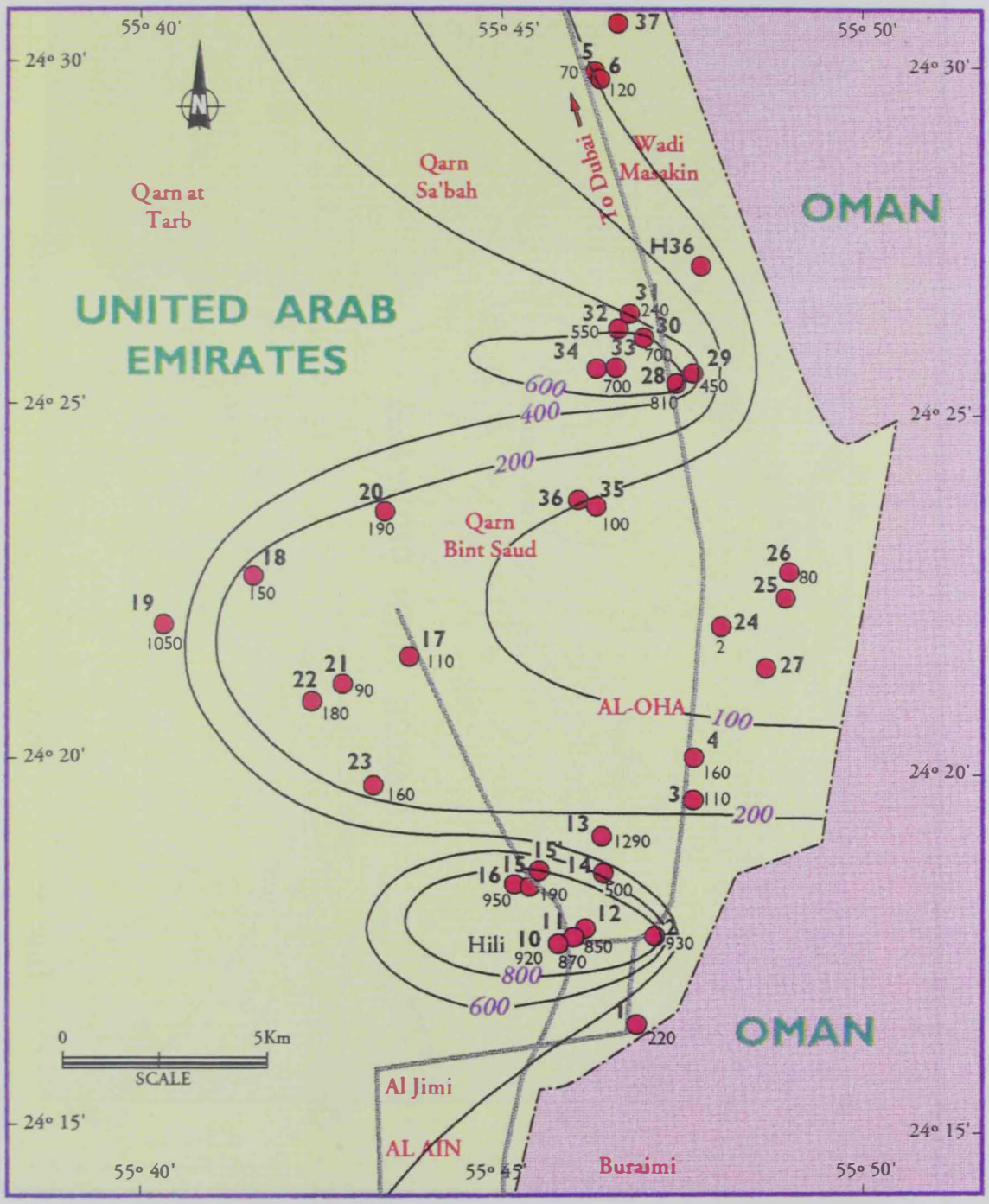

Figure 30. Iso-concentration contour map, mg/l, of the sulphate ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

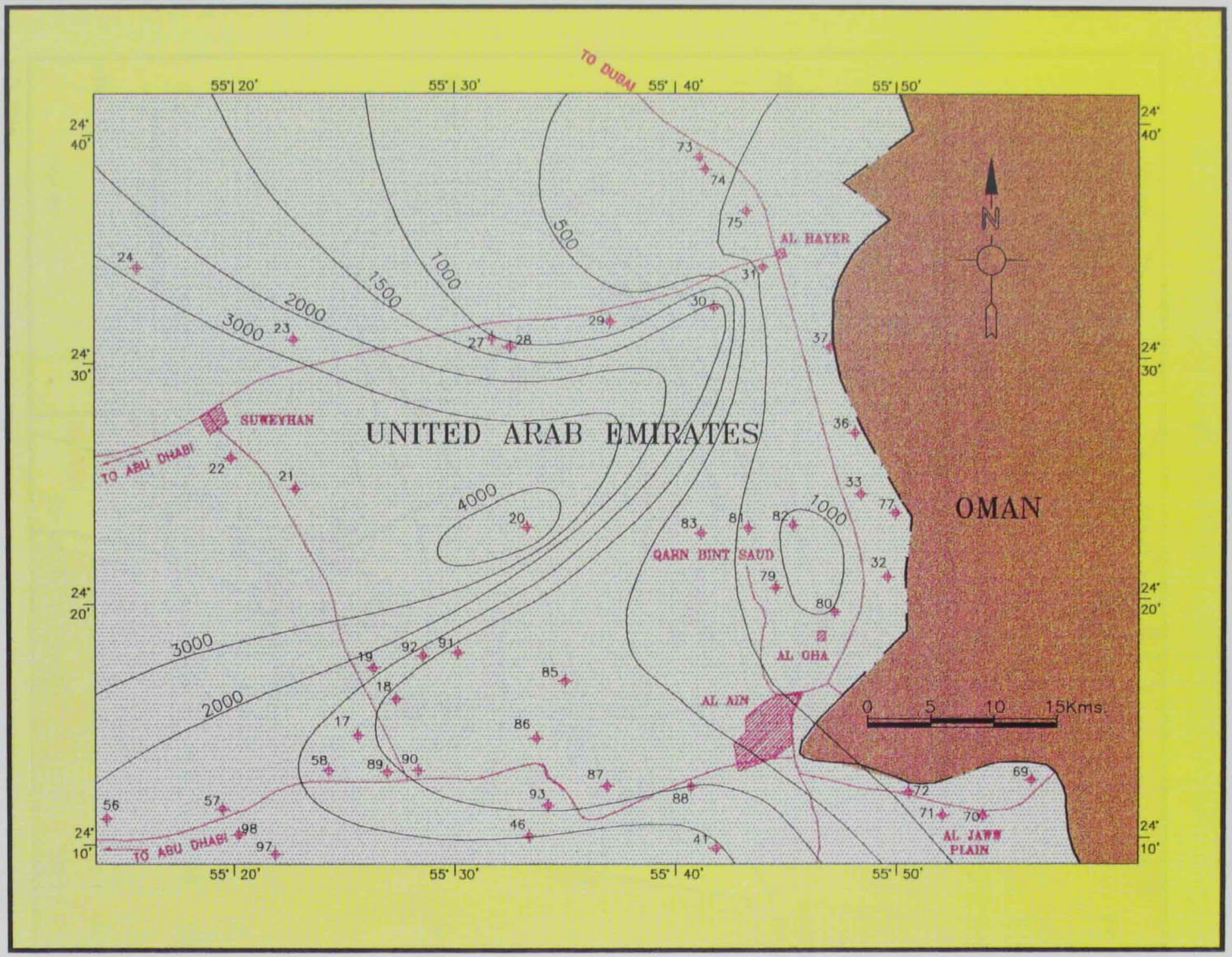

Figure 31. Iso-concentration contour map, mg/l, of the chloride ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

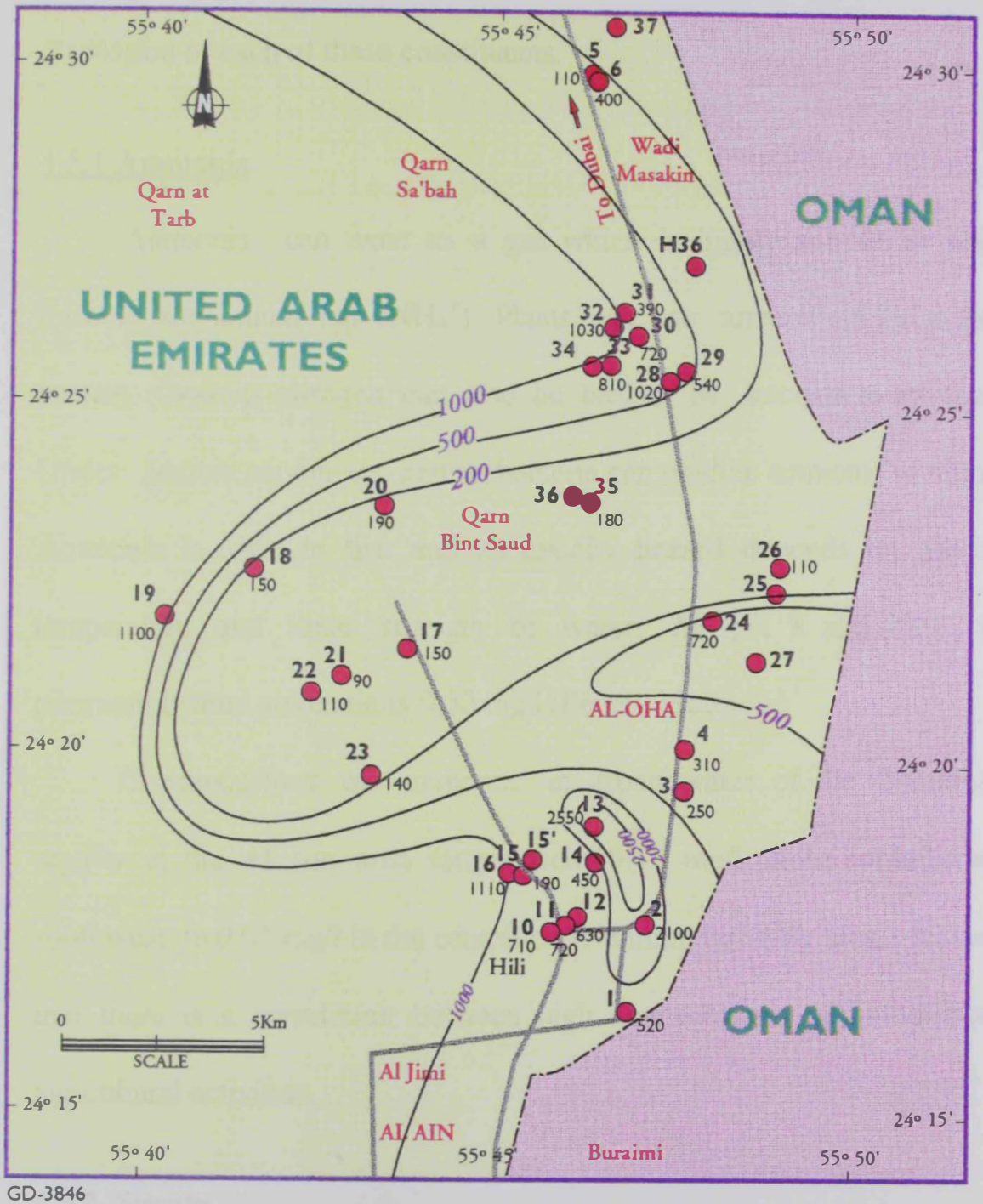

Figure 32. Iso-concentration contour map, mg/l, of the chloride ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

4.5 Minor Constituents

The minor constituents measured in this study include ammonia (NH_3), nitrates (NO_3^-) and phosphates (PO_4^{3-}). The following is a brief discussion of each of these constituents.

4.5.1 Ammonia

Ammonia can exist as a gas which is highly soluble in water forming ammonium ion (NH_4^+). Plants can use ammonium ion to form protein. Organic nitrogen can also be broken by bacteria to ammonia. Under aerobic conditions, certain bacteria can oxidize ammonia to nitrate. Ammonia is toxic to fish and its toxicity hazard depends on the pH, temperature and ionic strength of water. At pH 8 and 20°C, the permissible total ammonia is 0.52 mg/l (Fetter, 1988).

Concentrations of ammonia in groundwater of the Quaternary aquifer in the Al Ain area ranges from 0.15 mg/l in the northeast and southwest to 0.05 mg/l in the central part. Within the study area, it seems that there is a correlation between high concentration of ammonia and agricultural activities.

4.5.2 Nitrate

The dissolved nitrogen in form of nitrates ion (NO_3^-) is the most common contaminant identified in groundwater (Freeze and Cherry, 1979).

This is simply because the concentration of nitrate in groundwater is not limited by solubility constraints. Because of this and its ionic form, nitrate moves with groundwater with no transformation and little or no retardation.

Nitrate in groundwater generally originates from several natural and man-induced sources on the land surface, in the soil zone or in shallow subsoil zone. Nitrate nitrogen has proved to be a health hazard when it occurs in drinking water at concentrations in excess of 10 mg/l. Nitrate is reduced to nitrite (NO_2^-) in the gastrointestinal tract. The nitrite can then enter the bloodstream, whereupon it reacts with hemoglobin, impairing the blood's ability to transport oxygen. The WHO (1971) permissible limit for nitrate concentrations in drinking water is 10 mg/l of nitrate as nitrogen (Mc Cutcheon et al., 1993).

Nitrate-ion (NO_3^-) contents of groundwater samples collected from the Quaternary aquifer in the Al Ain area in February 1995 ranged from less than 5 mg/l in the eastern Al Ain area to 40 mg/l near the southeastern corner of the study area (Figure 33). Nitrate content exceded the WHO (1971) recommended limit for drinking water in only one well (Well no. 57) along Al Ain-Abu Dhabi road (Figure 34). The main source of nitrate in groundwater at this area is related to the application of chemical nitrogen fertilizers in agriculture.

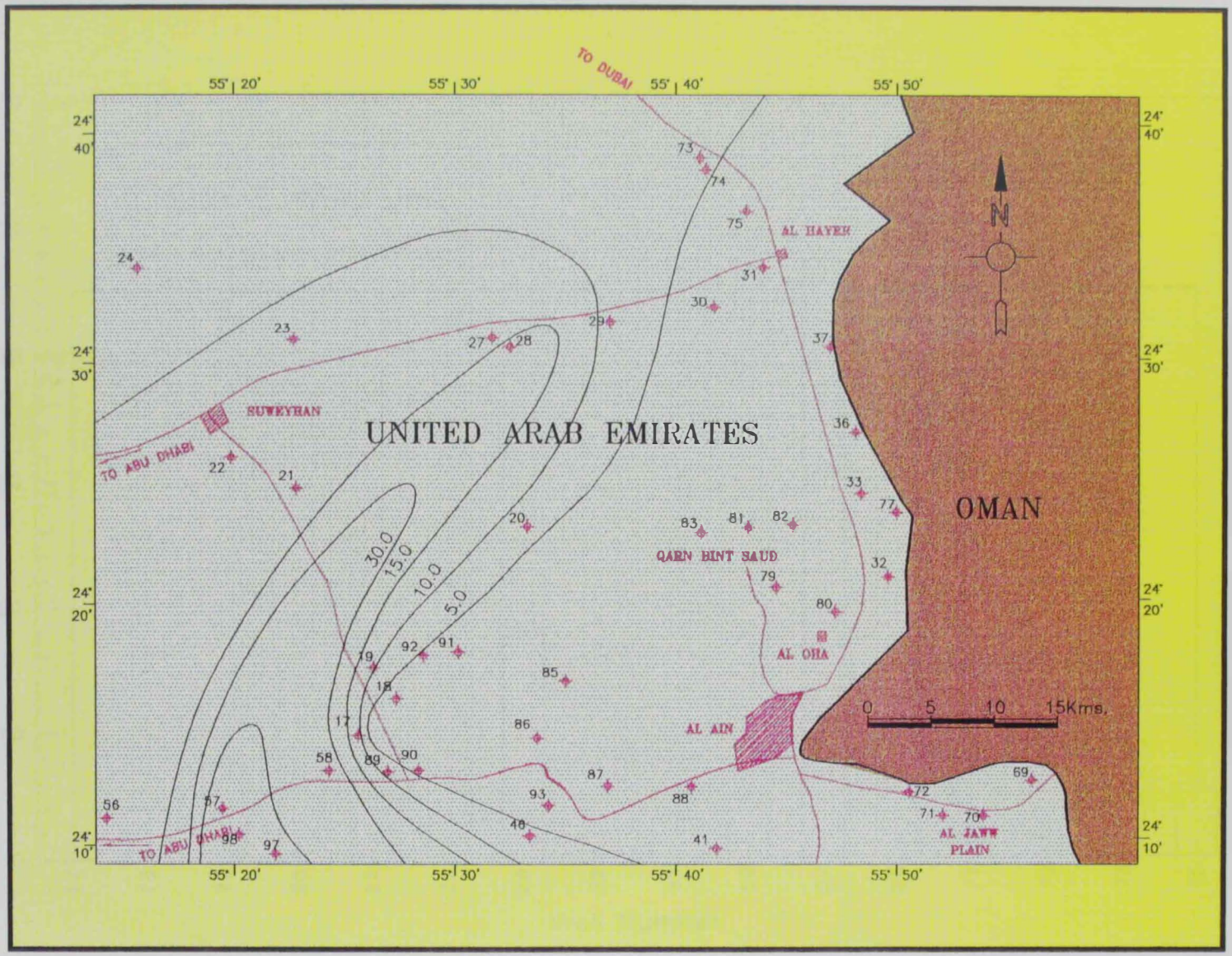

Figure 33. Iso-concentration contour map, mg/l, of the nitrate ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

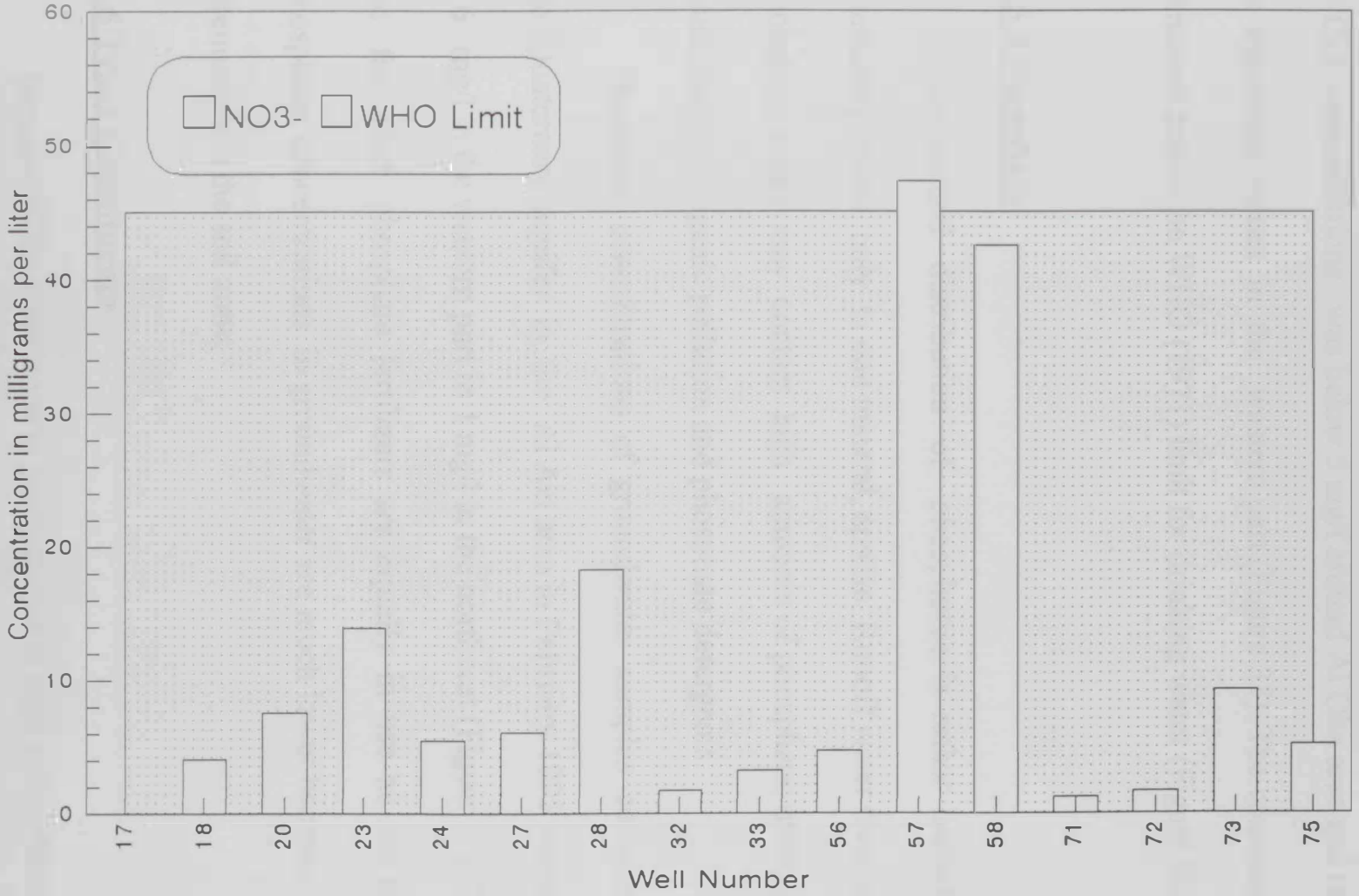

Figure 34. A bar graph showing the comparison between the nitrate ion concentration in Al Ain groundwater in February 1995 and the WHO limit for drinking water.

In the samples collected from Al Oha area in March 1996, the Nitrate-ion (NO_3^-) concentrations was below 5 mg/l around Al Oha area and reached its maximum values in the western part (Figure 35). The concentrations remained below the WHO (1971) limit for drinking water (Figure 36).

4.5.3 Phosphate

The natural distribution of phosphorus is rather limited; it is commonly found only in one mineral, apatite. Runoff water from areas of phosphate rocks may contain high amounts of phosphate; otherwise, its usual source is organic pollution and phosphate detergents.

Phosphate concentrations of groundwater samples collected from the Quaternary aquifer in the Al Ain area in February 1995 ranged from 0.6 mg/l in the western part to 1 mg/l in the northeast (Figuer 37). Despite the fact that phosphate fertilizers are equally in use as the nitrates, phosphate concentrations in groundwater are much lower because of their attenuation in the soil zone.

4.6 Trace Constituents

Because of their presence in groundwater at high concentrations has serious hazardous effects on human health, several trace metals were

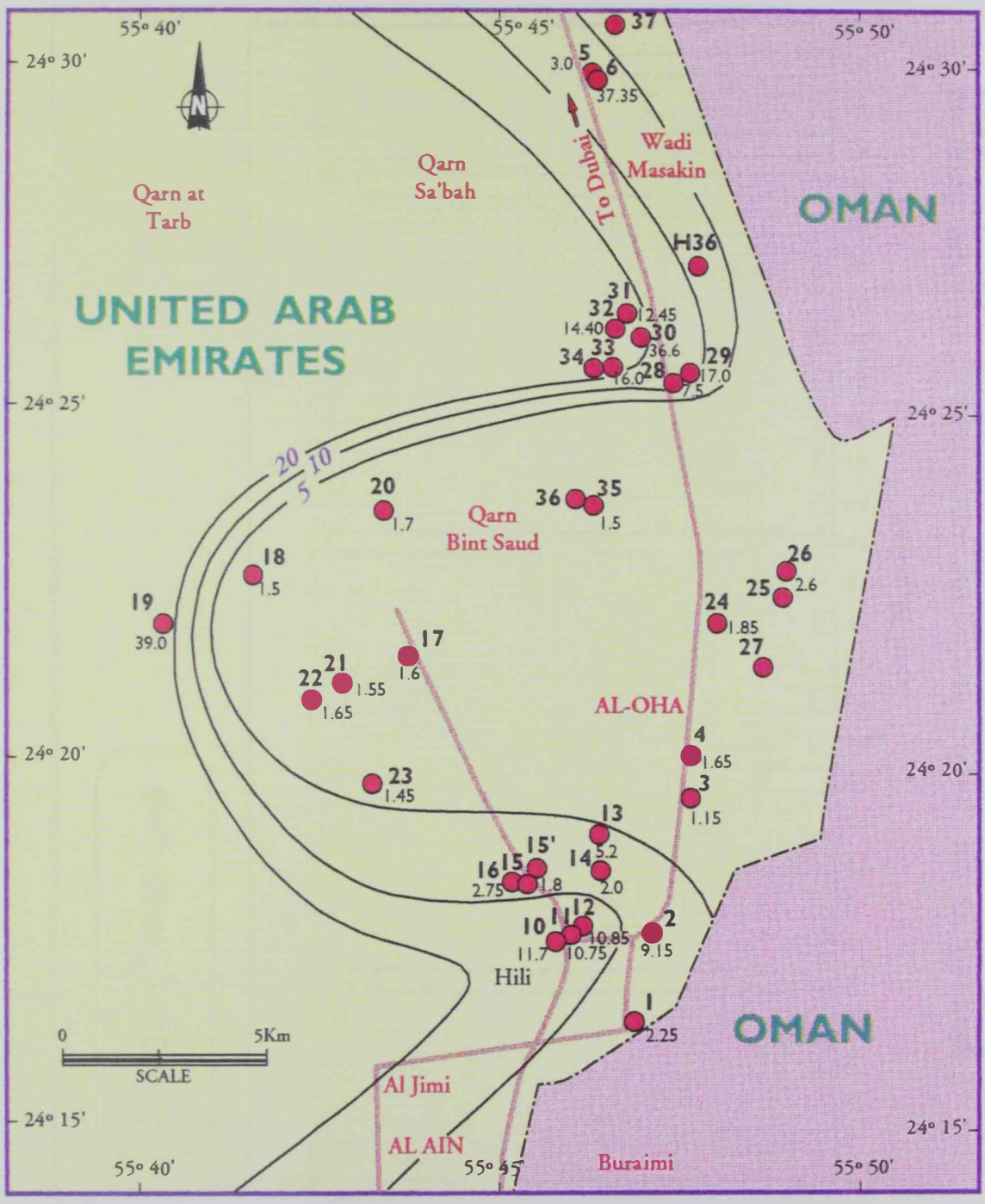

Figure 35. Iso-concentration contour map, mg/l, of the nitrate ion in groundwater of the Quaternary aquifer at Al Oha area in March 1996.

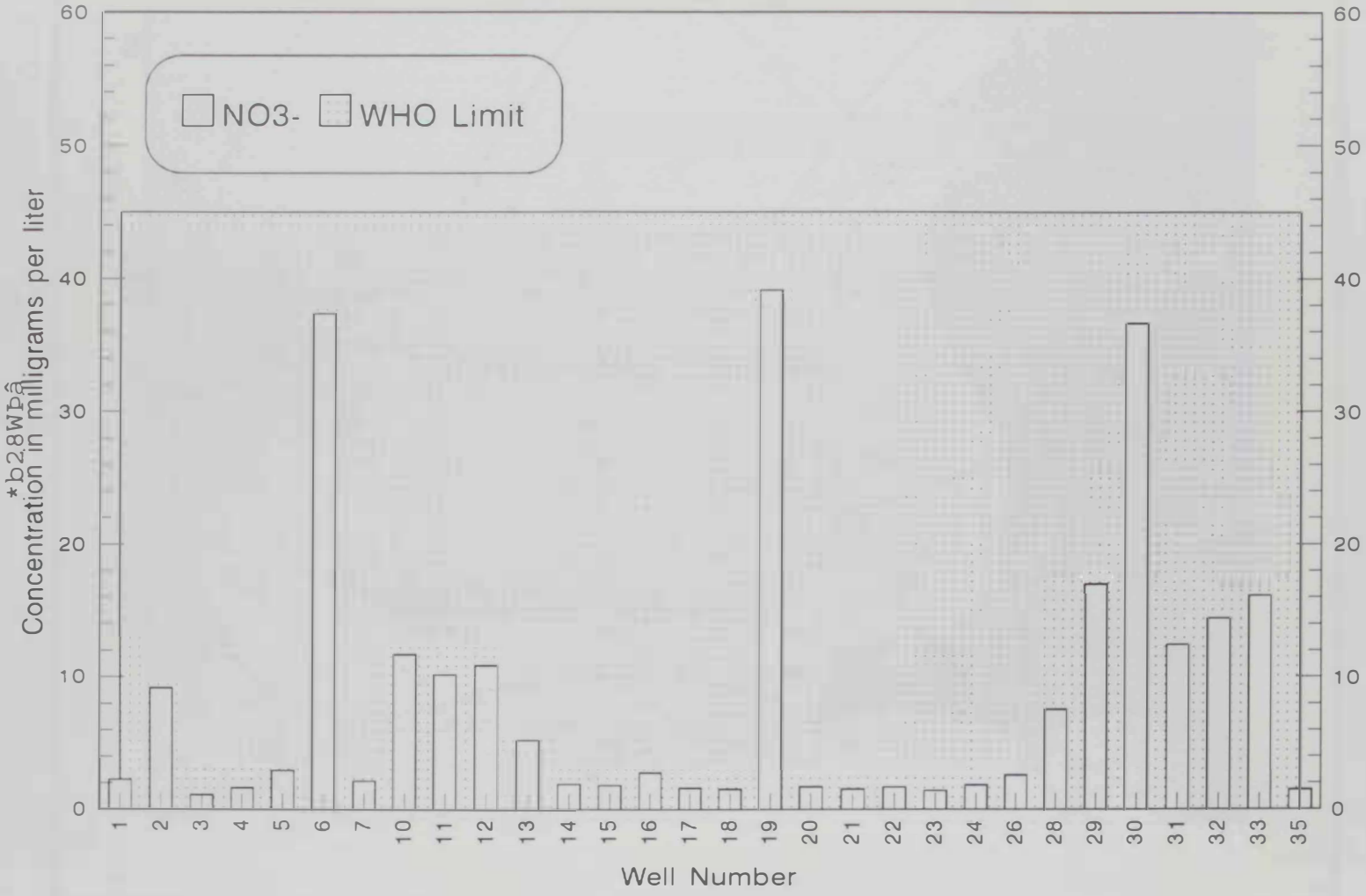

Figure 36. A bar graph showing the comparison between the nitrate ion concentration in Al Oha groundwater in March 1996 and the WHO limit for drinking water.

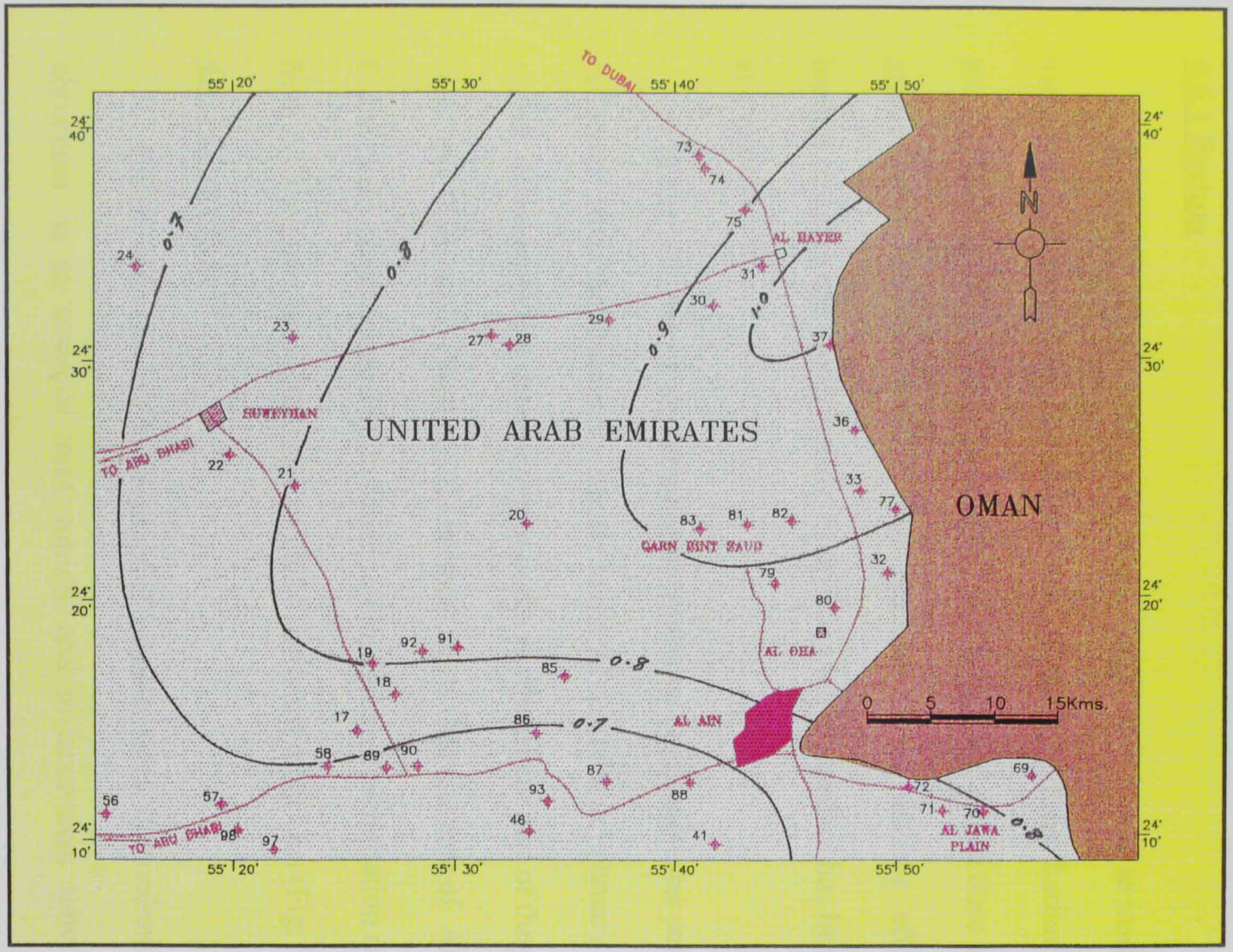

Figure 37. Iso-concentration contour map, mg/l, of the phosphate ion in groundwater of the Quaternary aquifer at Al Ain area in February 1995.

analyzed for in water samples collected from the Quaternary aquifer in the Al Ain area. The following is a brief discussion on each of these elements.

4.6.1 Barium

Barium is an alkaline earth metal occurring in nature as insoluble salts such as barite ($BaSO_4$) and witherite ($BaCO_3$). Soluble barium salts are poisonous, with a toxic dose of 0.2 to 0.6 mg/l and a fatal dose of 2.4 grams (Davis and De Weist, 1966). Because of the adverse effect of barium on heart and blood vessels, its drinking water standard has been set at 1 mg/l.

In the Al Ain area, barium concentrations in groundwater samples collected from the Quaternary aquifer in the Al Ain area in February 1995 varied between below detection limit in the northwestern part of the study area and 0.13 mg/l (Well no. 33) northest of Al Oha and east of Al Ain-Dubai road and (Figure 38). In March 1996, barium concentration ranged from 0.01 at Qarn Bint Saud mg/l and 0.14 northeast of Al Oha (Fig. 39).

4.6.2 Chromium

Chromium can exit in a number of valence states. In trivalent state, chromium is an essential trace nutrient and in hexavalent state, it is poisonous and corrosive. The toxicity of chromium is variable depending upon valency, water hardness and pH. The WHO (1971) standard for chromium concentration in drinking water is 0.1 mg/l.

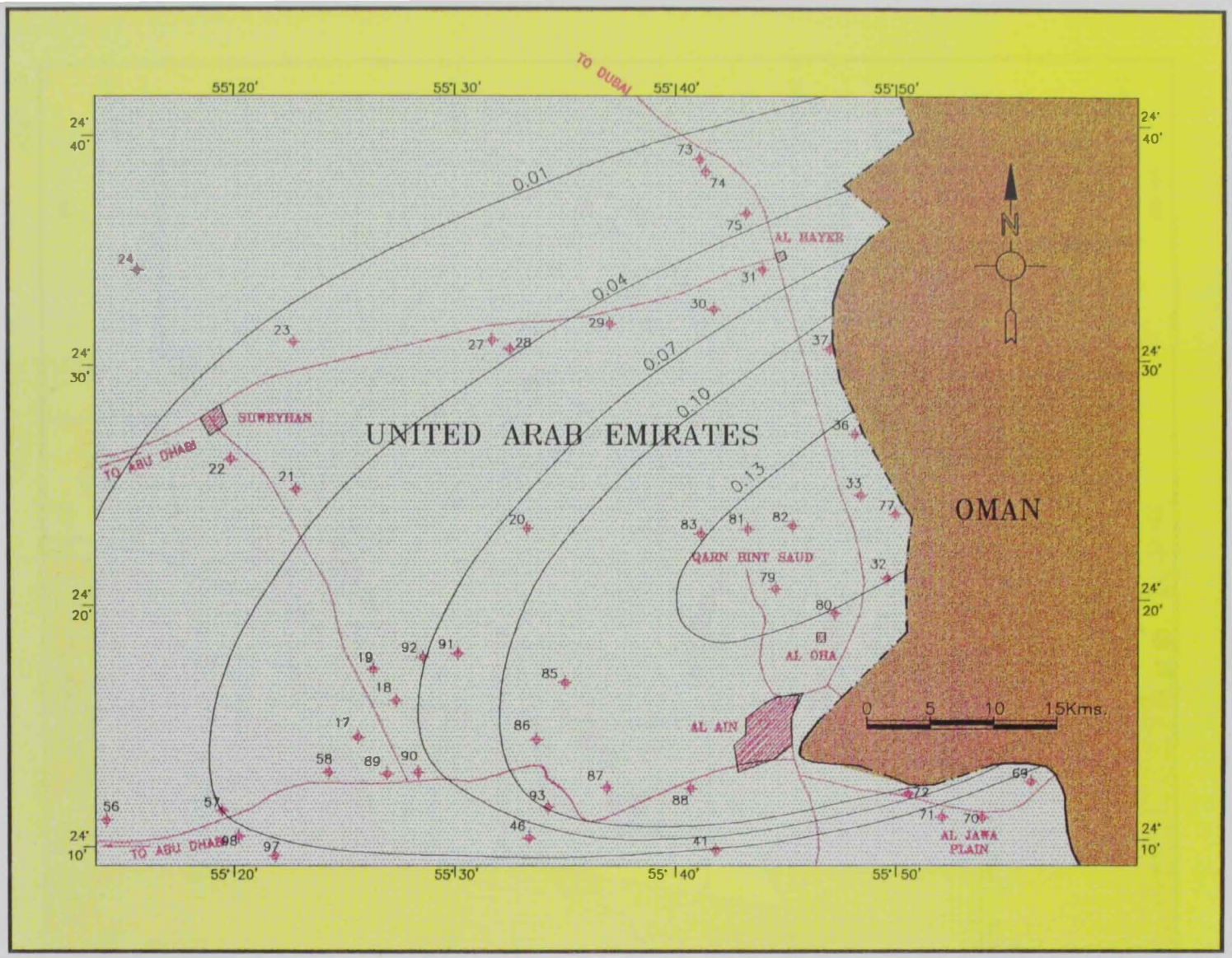

Figure 38. Iso-concentration contour map, mg/l, of the barium in Al Ain groundwater in February 1995.

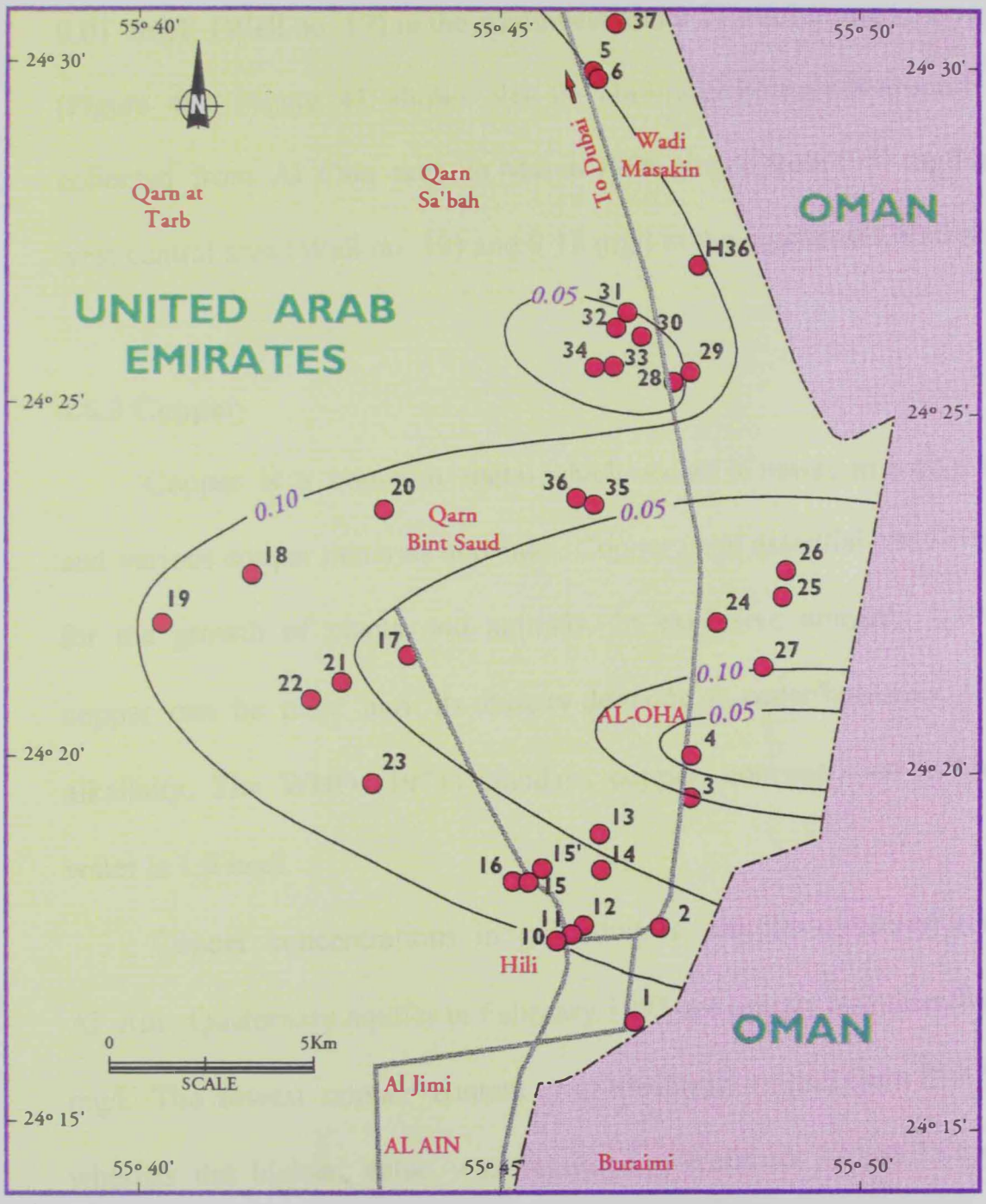

Figure 39. Iso-concentration contour map, mg/l, of the barium in Al Oha groundwater in March 1996.

Detected chromium concentrations in groundwater samples collected from the Quaternary aquifer in the Al Ain area in February 1995 varied between 0.01 mg/l (Well no. 17) in the southwest and 0.21 mg/l around Suweyhan (Figure 40). Figure 41 shows that the chromium content in groundwater collected from Al Oha area in March 1996 ranged from 0.01 mg/l in the west central area (Well no. 19) and 0.18 mg/l in the southeast (Well no. 1).

4.6.3 Copper

Copper is a common metal which occurs in nature as native metal and various copper minerals and salts. Copper is an essential trace element for the growth of plants and animals. In excessive amounts, however, copper can be toxic and its toxicity depends on water hardness, pH and alkalinity. The WHO (1971) standard copper concentration in drinking water is 1.0 mg/l.

Copper concentrations in groundwater samples collected from the Al Ain Quaternary aquifer in February 1995 are mostly less than the 0.05 mg/l. The lowest copper content was measured around Qarn Bint Saud, whereas the highset value was recorded in Wells no. 73 and 75 north of Al Hayer (Figure 42). In March 1996, copper concentrations in groundwater samples collected from the Al Oha area ranged from 0.03

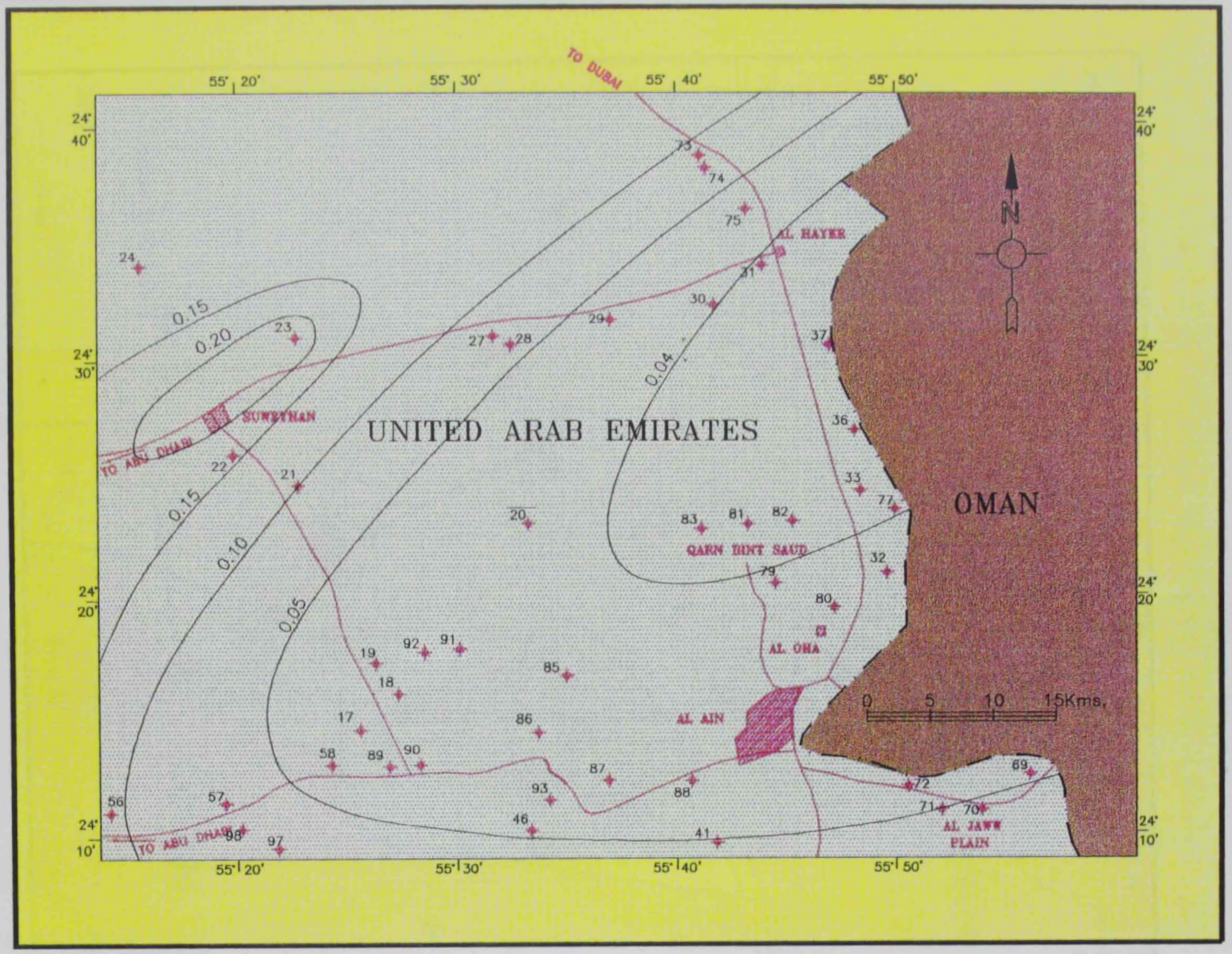

Figure 40. Iso-concentration contour map, mg/l, of the chromium in Al Ain groundwater in February 1995.

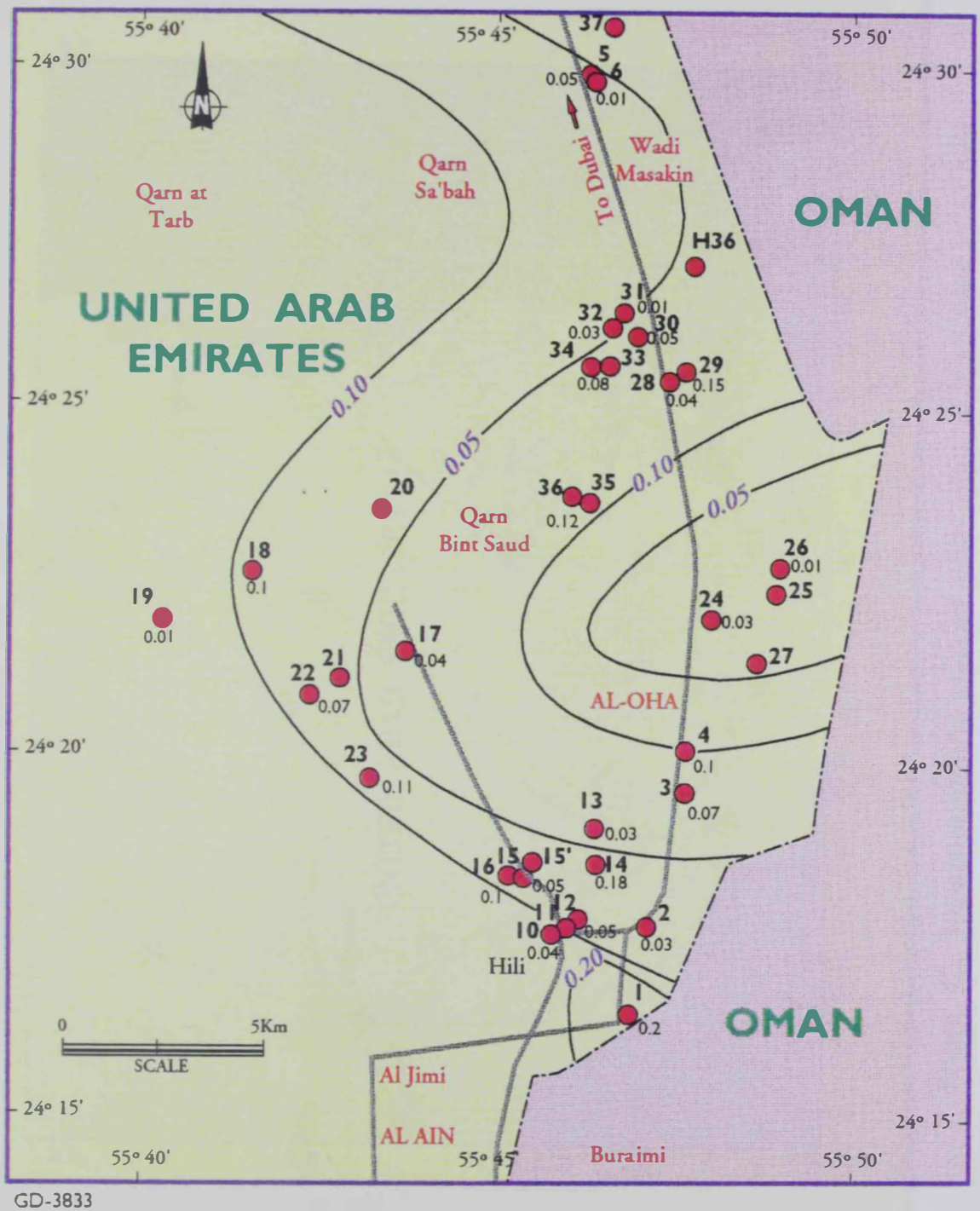

Figure 41. Iso-concentration contour map, mg/l, of the chromium in Al Oha groundwater in March 1996.

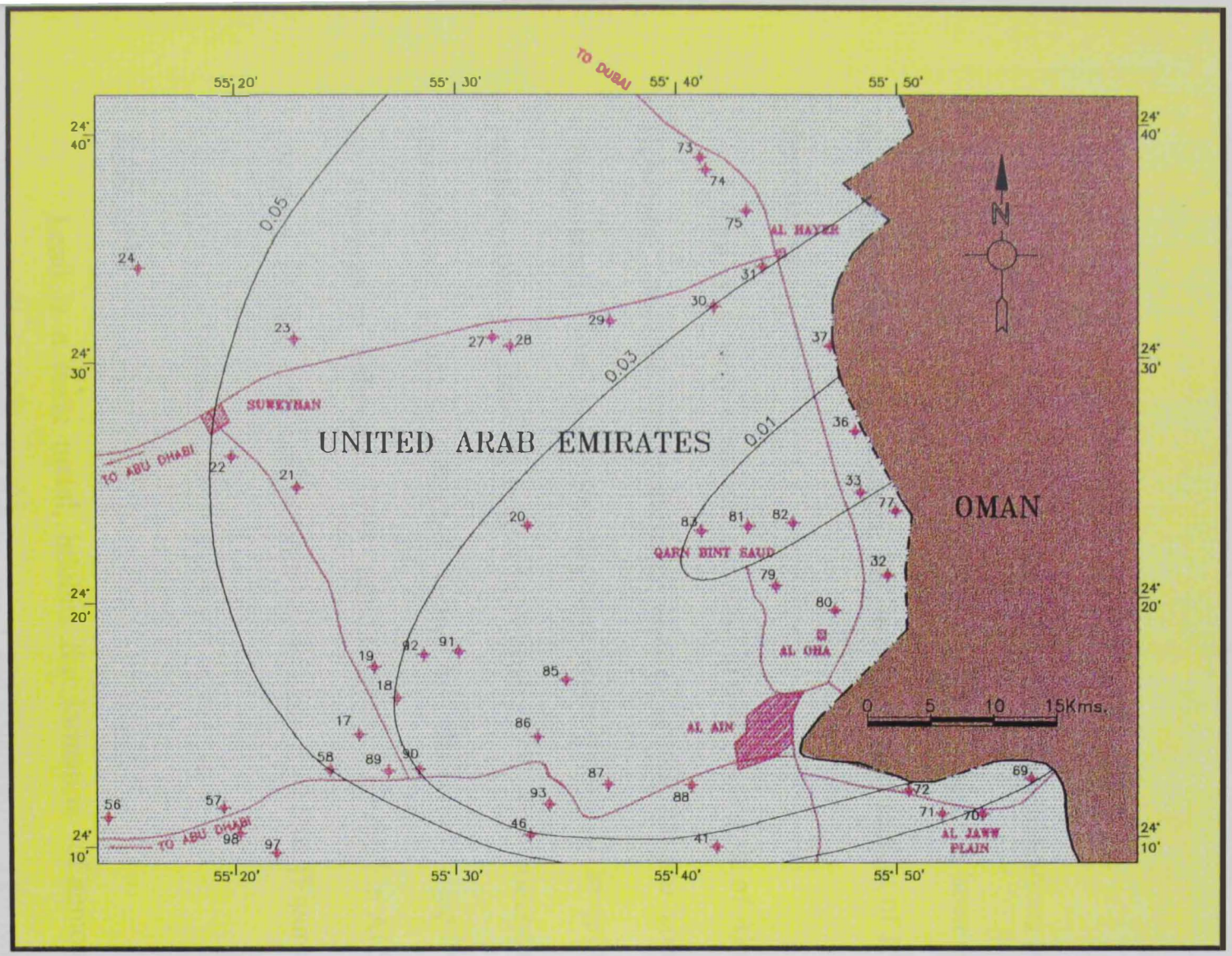

Figure 42. Iso-concentration contour map, mg/l, of the copper in Al Ain groundwater in February 1995.

mg/l in the northeast (Well no. 29) and 0.18 mg/l in Well no. 4 at Al Oha area (Figure 43).

4.6.4 Iron

Iron is toxic to some aquatic species at concentrations of 0.32 to 1.00 mg/l. A water quality criterion for iron of 0.3 mg/l has been suggested for domestic uses. For aquatic life, maximum iron content of 1.0 mg/l is the criterion.

Iron is a very common element in rocks and soils of Al Ain area. However, because the Quaternary aquifer in the Al Ain area is free (oxygenated), low iron concentrations were measured in groundwater samples collected from the aquifer in February1995. Iron concentrations in groundwater samples collected from the Quaternary aquifer in the Al Ain area in February 1995 varied between 0.03 mg/l in Al Saad area (Well no. 18) and 1.54 mg/l in Well no. 32 east of Al Oha (Figure 44).

4.6.5 Lead

Lead is a toxic metal, inhibits the formation of hemoglobin and accumulates in bone and soft tissues. Lead poisoning is a known cause of mental retardation, central palsy and potic nerve atrophy in children. For

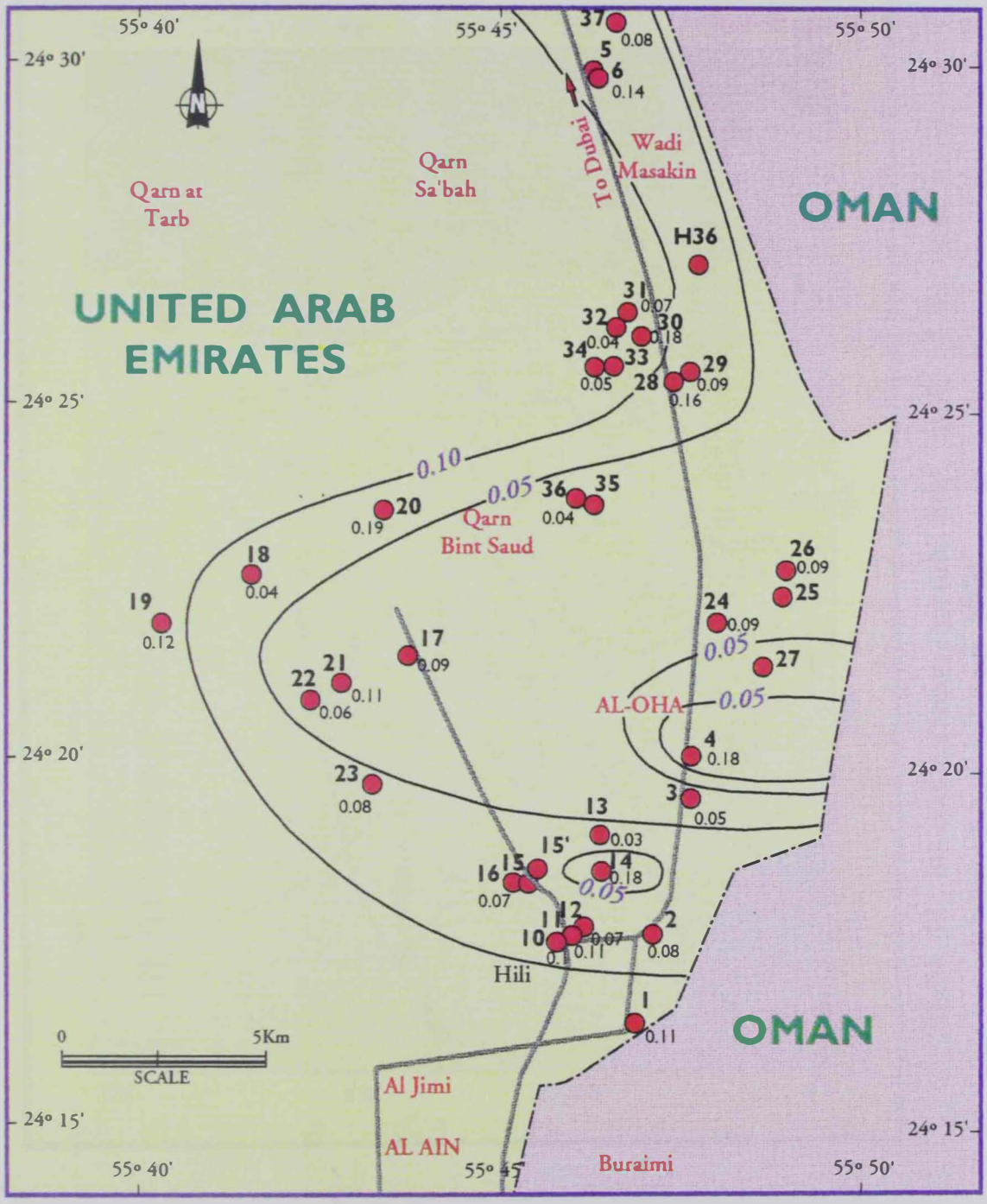

Figure 43. Iso-concentration contour map, mg/l, of the copper in Al Oha groundwater in March 1996.

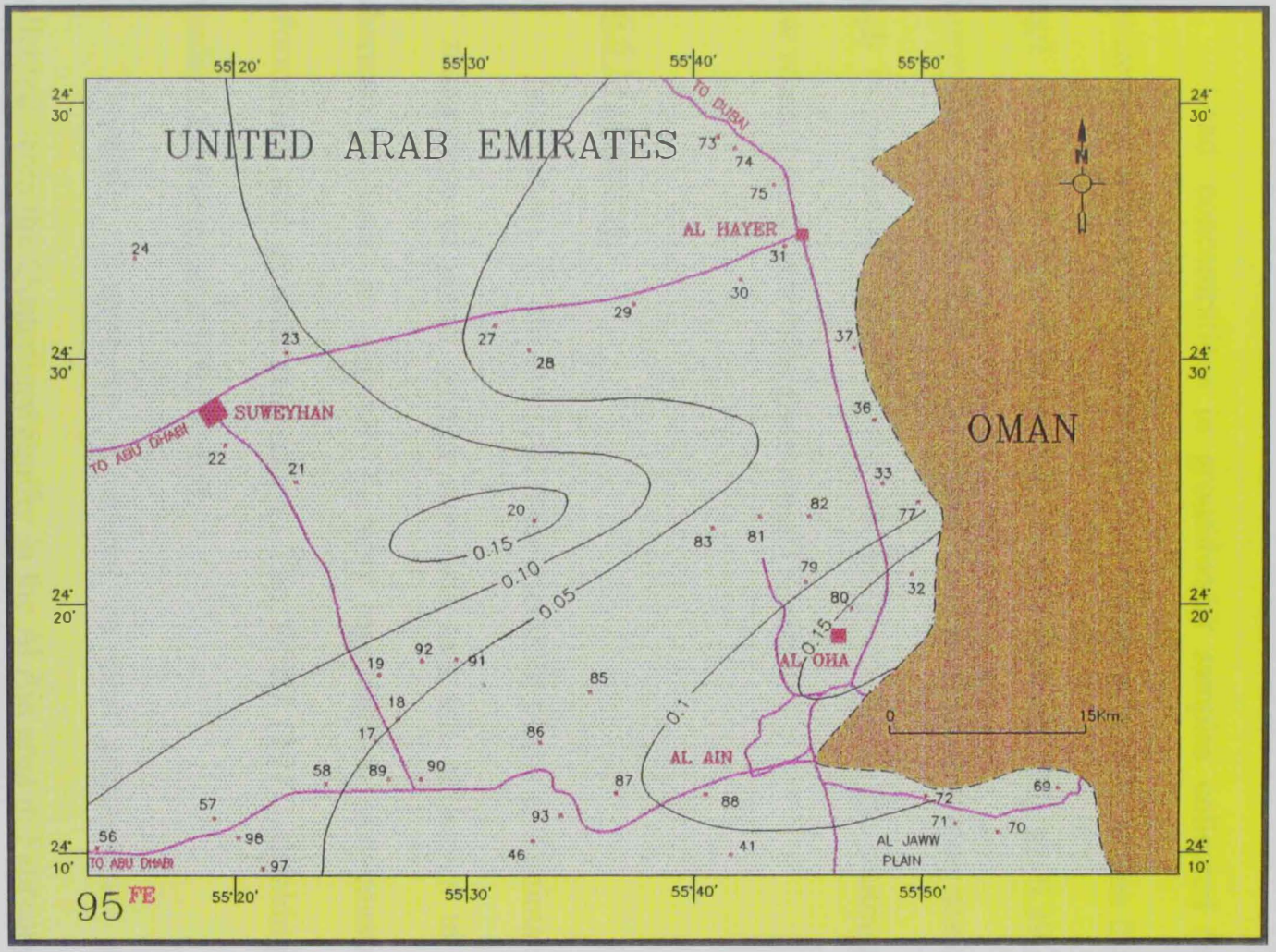

Figure 44. Iso-concentration contour map, mg/l, of the iron in Al Ain groundwater in February 1995.

these reasons, the lead drinking water quality standard is as low as 0.05 mg/l.

Lead concentrations in groundwater samples collected from the Quaternary aquifer in the Al Ain area in February 1995 ranges from 0.01 mg/l along Al Hayer-Suweyhan road (Well no. 28) to 0.39 around Suweyhan city (Well no. 23). Lead content in groundwater seems to be high in residential areas, in the east and northwest in the southwest, and low where human activities are minmal (Figure 45).

4.6.6 Manganese

Manganese is an essential trace metal for plants and animals. Lack of manganese in plants causes chlorosis and fall of leaves in plants; whereas its lack in animals disrupts reproduction and causes bone deformation and growth retardation. The WHO (1971) drinking water standard for manganese is 0.05 mg/l.

Generally, manganese is absent in most groundwater samples collected from the Quaternary aquifer in the Al Ain area in February 1995. The manganese content in groundwater within the study area is well below the WHO (1971) recommended limit for drinking water (Figure 46).

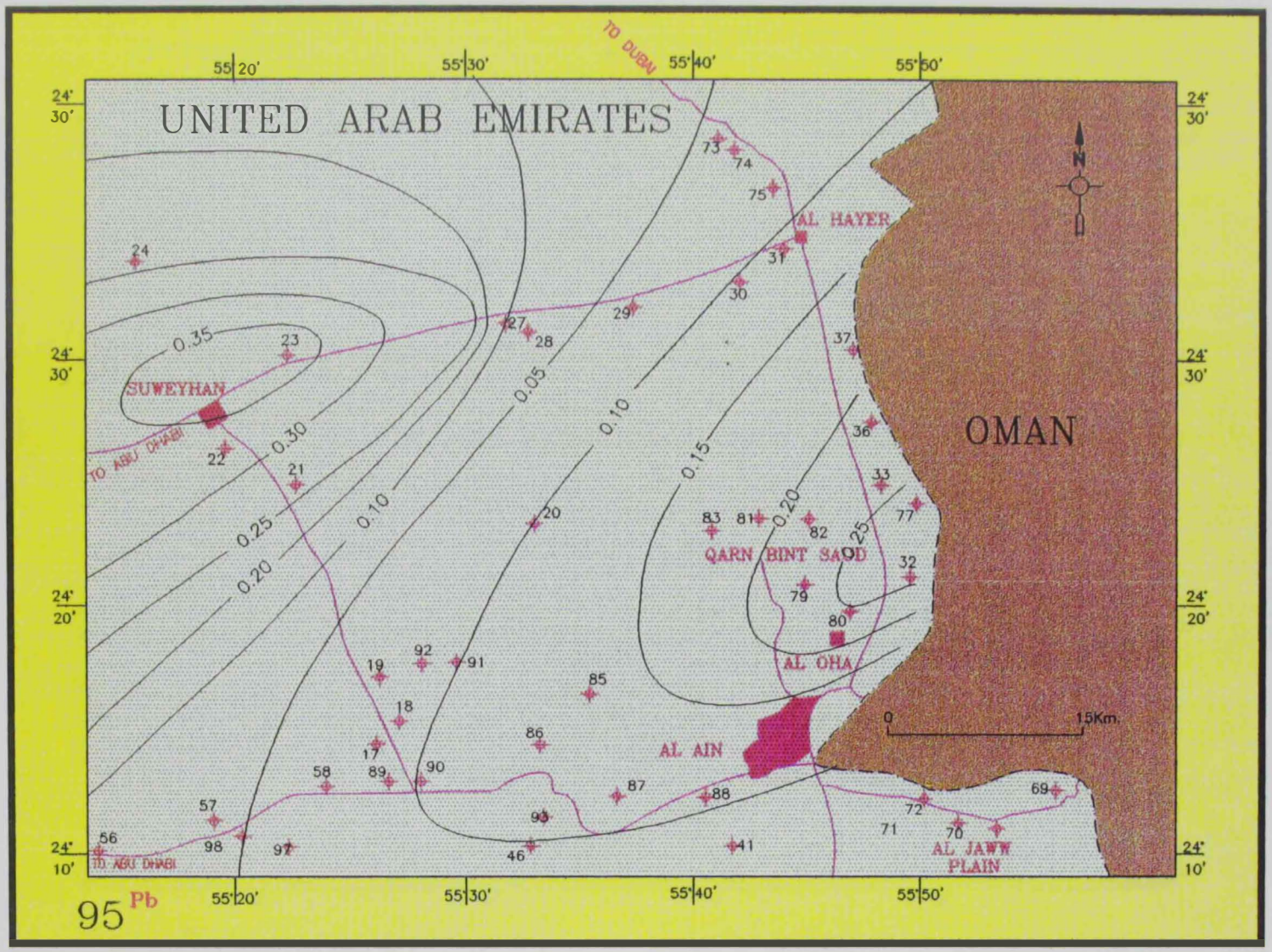

Figure 45. Iso-concentration contour map, mg/l, of the lead in Al Ain groundwater in February 1995.

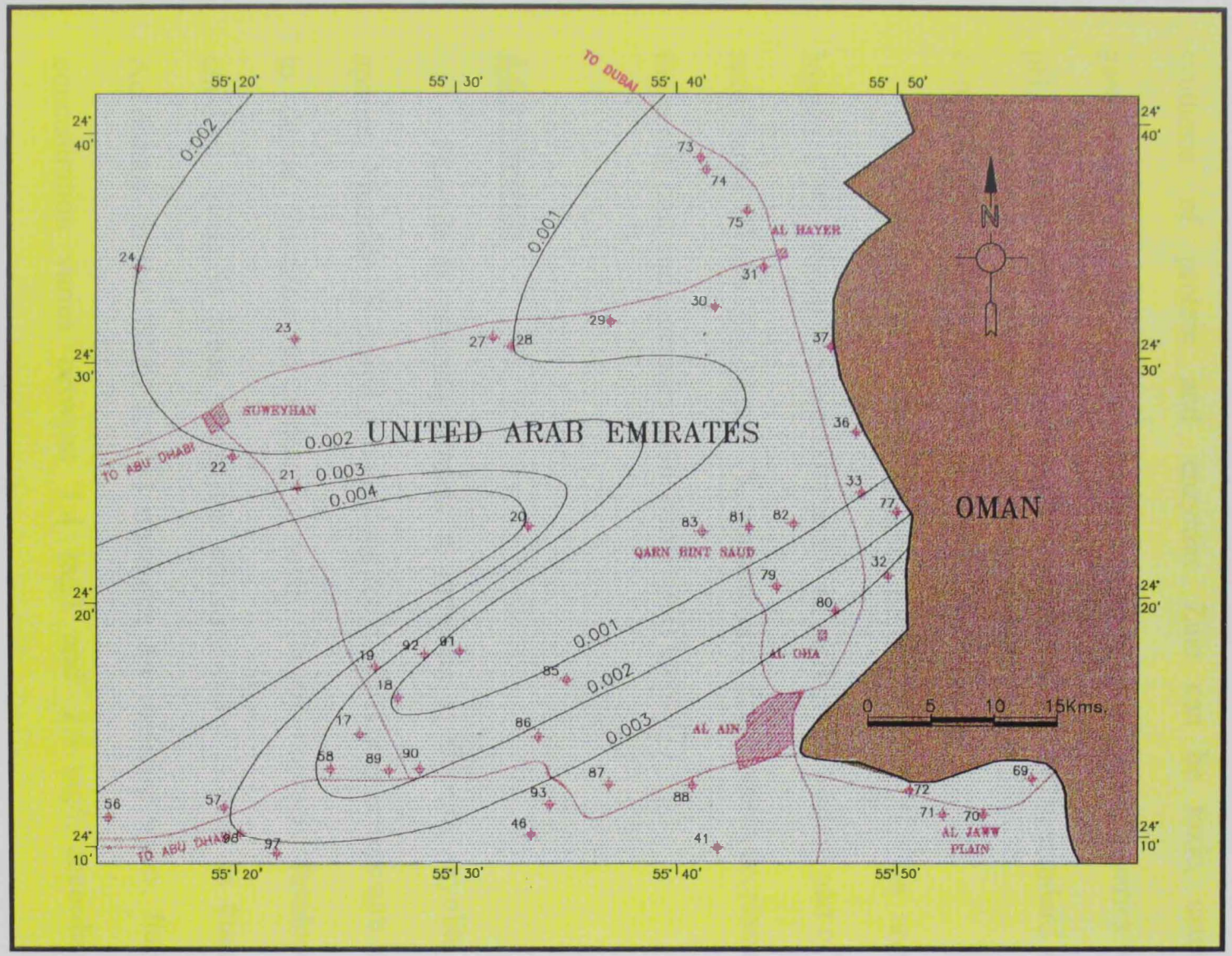

Figure 46. Iso-concentration contour map, mg/l, of the manganese in Al Ain groundwater in February 1995.

4.6.7 Zinc

Zinc is an essential trace element necessary for human metabolism, synthesis of protein and enzymes. Zinc can be toxic, causing gastrointestinal distress if ingested in large quantities. Toxicity varies with pH, alkalinity and water hardness. Suggested WHO (1971) standard zinc concentration in drinking water is 5 mg/l.

Zinc measured in water samples collected from Al Oha area in March 1996 varied between 0.04 and 0.42 mg/l in the western part of the study area (Wells no. 18 and 19, respectively). Zinc content decreases in the cental part and increases again eastward (Figure 47).

4.6.8 Fluoride

Fluoride is naturally present in minerals as fluorite, cryolite and apatite. Fluoride is stored in bones and teeth. Chronic overexposure leads to dental fluorosis or nottling of teeth. Dental fluorosis develops in children living in areas where the drinking water is high in fluoride. According to the WHO (1971) standards for drinking water, fluoride concentration varies between 1.4 mg/l and 2.4 mg/l, according to prevailing temperature.

Fluoride values of groundwater collected from Al Ain groundwater in February 1995 varied between 0.67 mg/l east of Al Oha area (Well no.

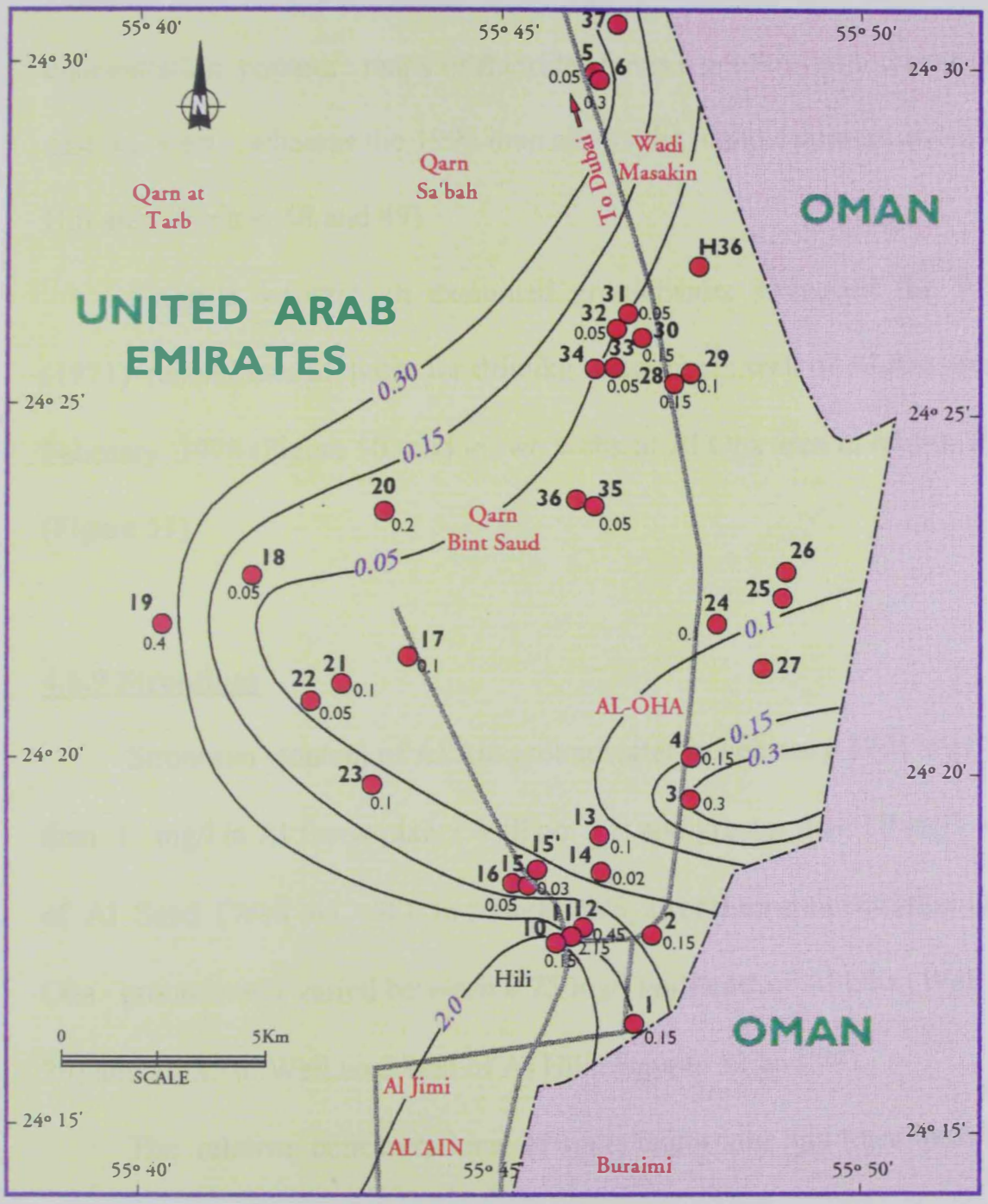

Figure 47. Iso-concentration contour map, mg/l, of the zinc in Al Oha groundwater in March 1996.

32) and 9.32 mg/l in the central part (Well no. 20). In the March 1996 samples fluoride contents were 0.27 mg/l in Well no. 5 north of Wadi Masakin and 4.64 mg/l north of Al Hili (Well no. 5). The 1995 iso-concentration contour maps of fluoride shows a continuous increase from east to west, whereas the 1996 map shows the highest content around Al Hili area (Figures 48 and 49).

Fluoride content in examined groundwater exceeded the WHO (1971) recommended limit for drinlikg water in six well of Al Ain area in February 1995 (Figure 50) and in two wells of Al Oha area in March 1996 (Figure 51).

4.6.9 Strontium

Strontium content of Al Ain groundwater in February 1995 was less than 1 mg/l in Al Jaww plain (Well no. 72) and greater than 10 mg/l west of Al Saad (Well no. 58). In March 1996, strontium concentration in Al Oha groundwater varied between 0.75 mg/l northeast of Al Oha (Well no. 26) and 16.35 in Well no.2 east of Al Hili (Figures 53 and 54).

The relative concentrations of some major ions and trace metals in Al Ain (February 1995) and Al Oha (March 1996) groundwater to the WHO (1971) limits are shown in Appendix C (Parts 1 and 2).

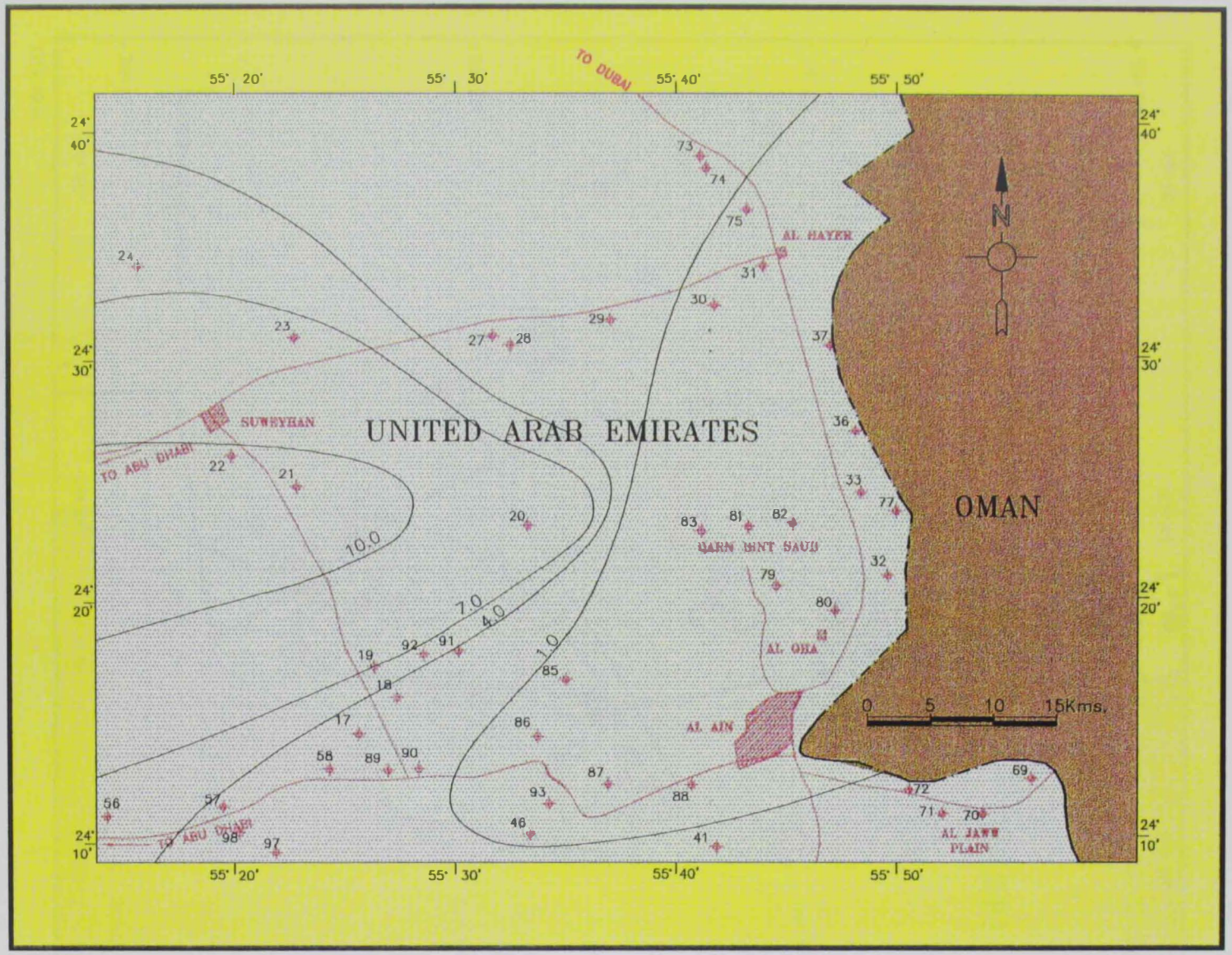

Figure 48. Iso-concentration contour map, mg/l, of the fluoride in Al Ain groundwater in February 1995.

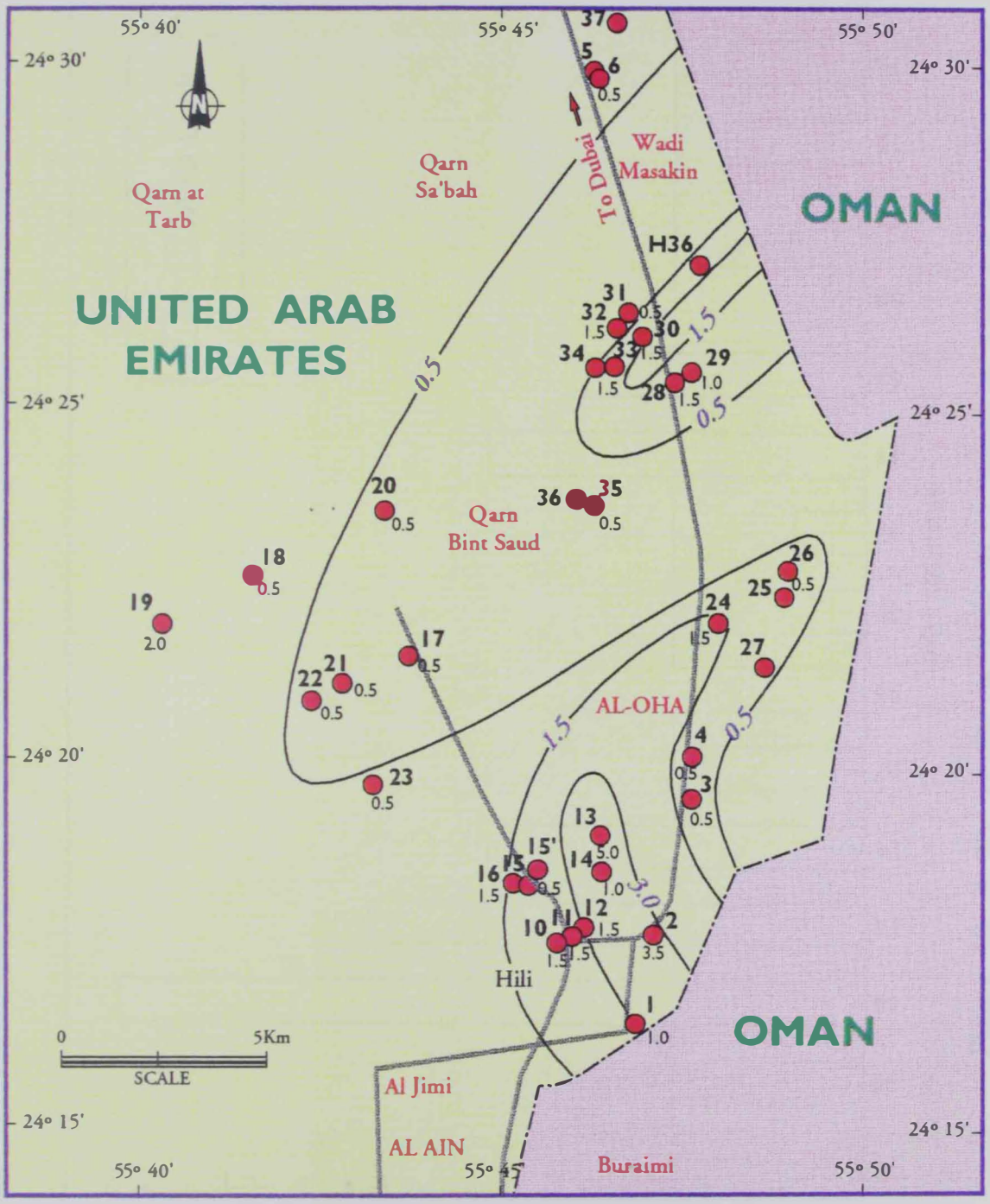

Figure 49. Iso-concentration contour map, mg/l, of the fluoride in Al Oha groundwater in March 1996.

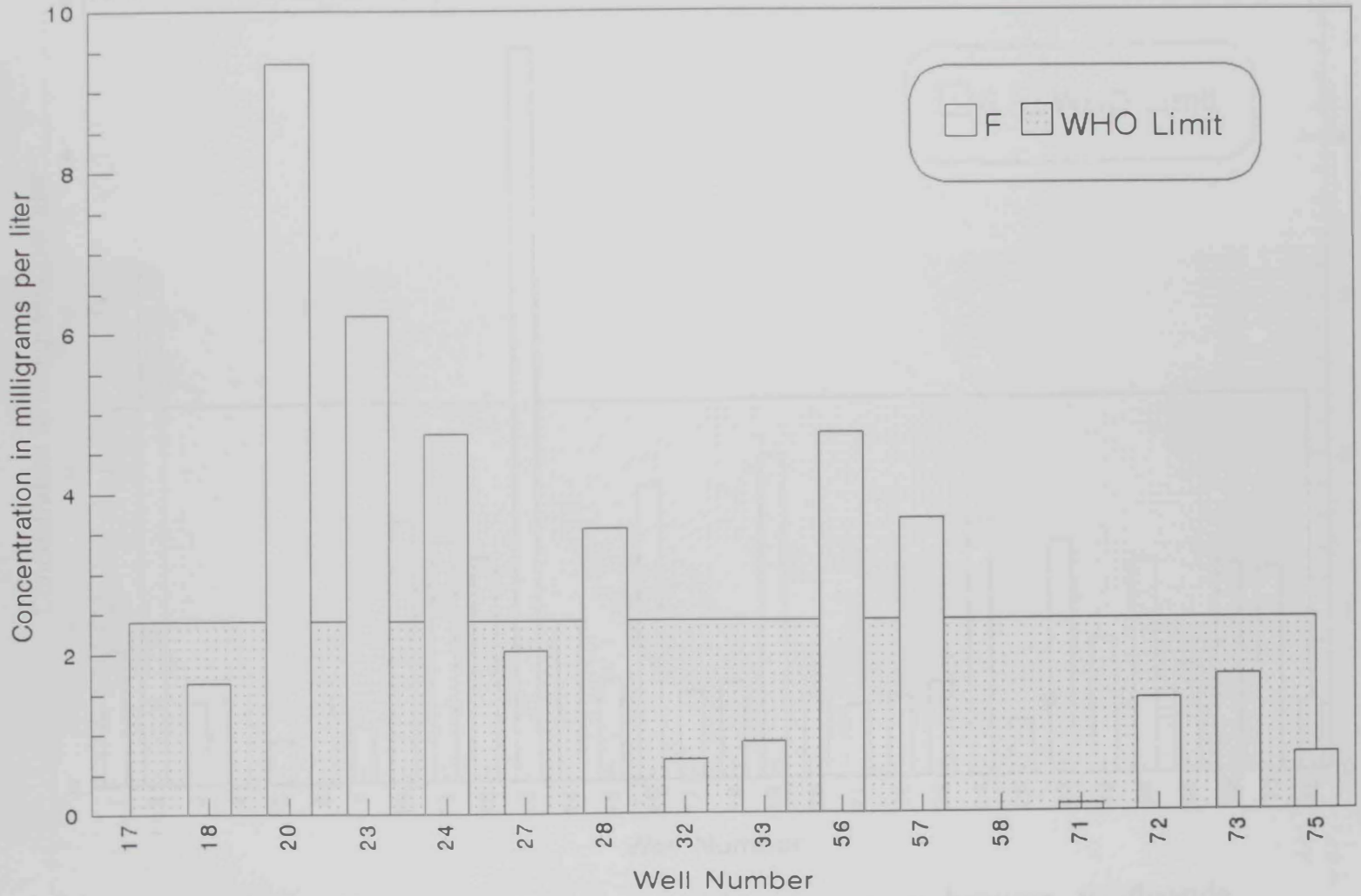

Figure 50. A bar graph showing the comparison between the fluoride concentration in Al Ain groundwater in February 1995 and the WHO limit for drinking water.

Figure 51. A bar graph showing the comparison between the fluoride concentration in Al Oha groundwater in March 1996 and the WHO limit for drinking water.

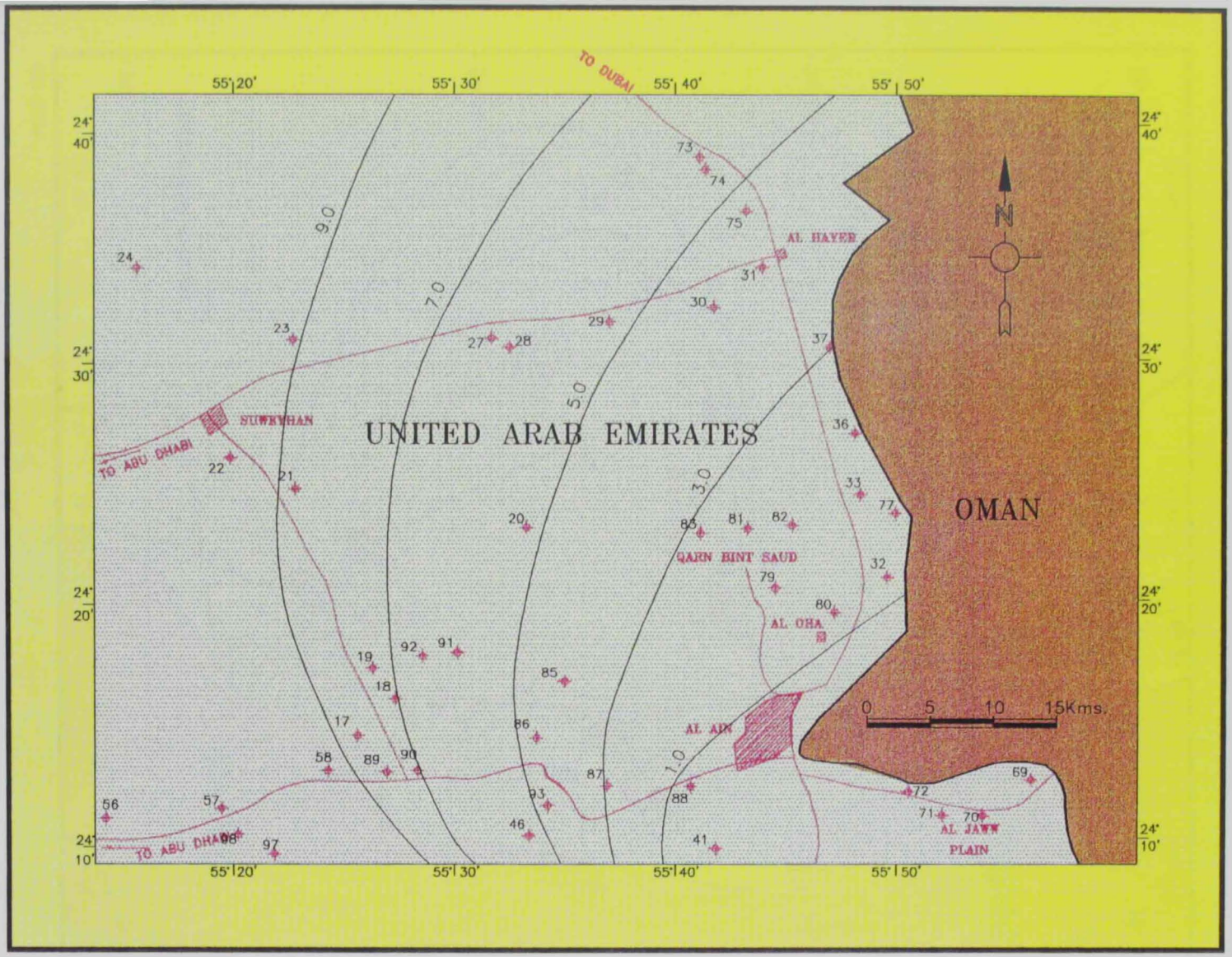

Figure 52. Iso-concentration contour map, mg/l, of the strontium in Al Ain groundwater in February 1995.

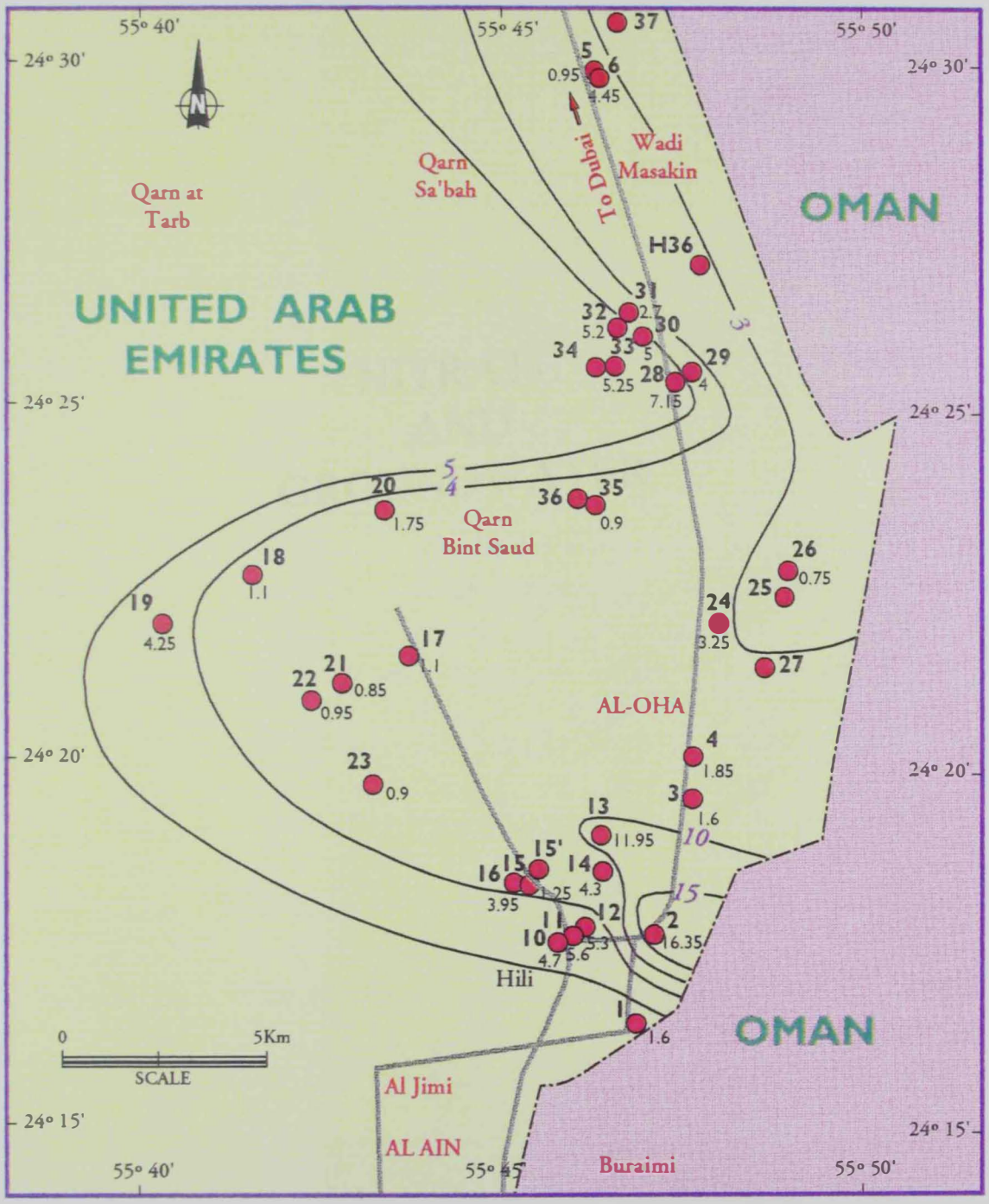

Figure 53. Iso-concentration contour map, mg/l, of the strontium in Al Oha groundwater in March 1996.

CHAPTER V

NITRATE AND GROUNDWATER

CHAPTER V

NITRATE AND GROUNDWATER

The dissolved nitrogen in the form of nitrate (NO_3^-) is the most common contaminant identified in groundwater (Freeze and Cherry, 1979). This is because the concentration of nitrate in groundwater is not limited by solubility constraints. Because its ionic form and unlimited solubility, nitrate is very mobile and moves in the groundwater with no transformation and little or no retardation.

Nitrate in groundwater generally originates from nitrate sources on the land surface, in the soil zone or in shallow subsoil zone (Figure 54), where nitrogen-rich wastes are buried (Freeze and Cherry, 1979). Nitrate is the end product of sewage disposal, because of the microbial breakdown of the nitrogenous compounds in the excerta. In some situations, nitrate that enters the groundwater system originates as (NO_3^-) in wastes or fertilizers applied to land surface. These are designated as direct nitrate in groundwater in high concentration is undesirable and threatening large aquifer systems in many parts of the world (Freeze and Cherry, 1979).

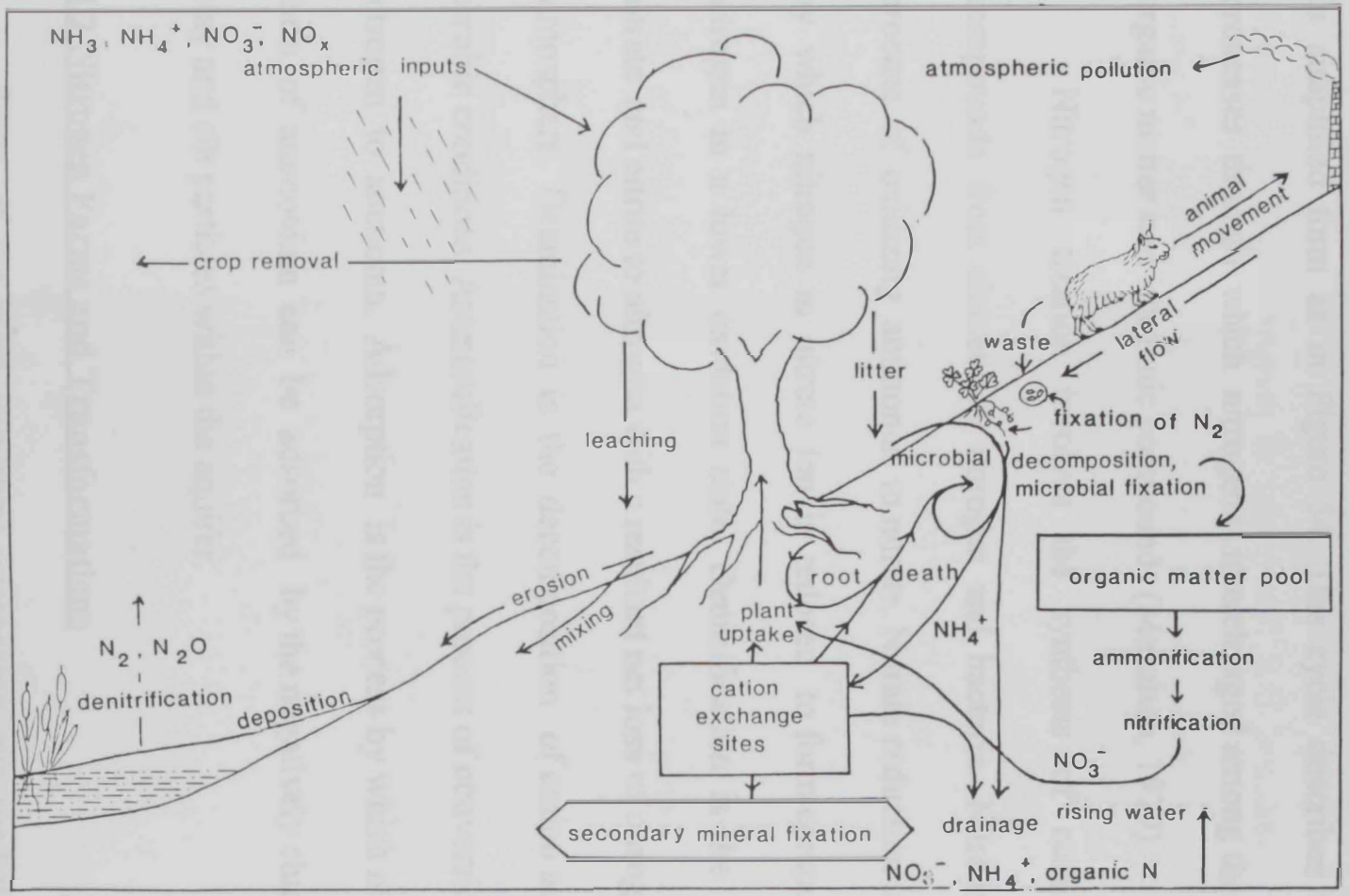

Figure 54. Nitrogen cycle (Cresser et al., 1993).

4.1 Nitrogen Cycle

The nitrogen cycle is complex, but can be portrayed schematically in simplified form as in Figure 54. This cycle describes the dynamic processes through which nitrogen is interchanged among the atmosphere, organic matter and inorganic compounds (Manahan, 1979).

Nitrogen fixation involves the synthesis of cellular nitrogen compounds from elementary nitrogen and bacteria. Nitrification is the process of oxidizing ammonia to nitrate. Nitrate reduction is the process by which nitrogen in nitrate ion is reduced to form compounds having nitrogen in a lower oxidation state. Denitrification is the reduction of nitrate and nitrite to nitrogen with a resultant net loss of nitrogen gas to the atmosphere. Deamination is the decomposition of amino acids under an aerobic conditions. Ammonification is the process of conversion of organic nitrogen to ammonia. Adsorption is the process by which nitrogen in the form of ammonium can be adsorbed by the negatively charged sites on clay and silt particles within the aquifer.

4.2 Nitrogen Forms and Transformations

Some of the most important microorganisms mediated chemical reactions in aquatic and soil environments are those involving nitrogen compounds (Manahan, 1979).

4.2.1 Nitrification

Nitrification is the conversion of N^{3+} to N^{4+} is a very common and extremely important process in water and soil. In nature, nitrification is catalyzed by two groups of bacteria; *Nitrosomanas* and *Nitrobacter*. *Nitrosomanas* bacteria bring about the transition of ammonia to nitrate according to the following reaction:

$$NH_3 + 3/2\ O_2 \text{ ---------> } NO_3^- + H^+ + H_2O \qquad (2)$$

whereas, *nitrobacter* bacteria mediates the oxidation of nitrite to nitrate.

$$NO_2^- + 1/2\ O_2 \text{ --------> } NO_3^- \qquad (3)$$

Both of *nitrosomanas* and *nitrobacter* are aerobic bacteria which function only in presence of molecular oxygen. For aerobic conversion of ammonical nitrogen to nitrate at pH 7,

$$1/6\ NH_4 + 1/4\ O_2 \text{ --------> } 1/6\ NO_2 + 1/3\ H^+ + 1/6\ H_2O \qquad (4)$$

then the conversion of nitrite to nitrate,

$$1/2\ NO_2 + 1/4\ O_2 \text{ --------> } 1/2\ NO_3^-. \qquad (5)$$

4.2.2 Ammonification

Ammonification is the process of conversion of organic nitrogen to ammonium (Freeze and Cherry, 1979). The ammonification of amino acids

requires oxygen to be present (Fetter, 1977). This reaction can be represented as follows:

Organic nitrogen --------> Ammonium (NH_4) (6)

4.2.3 Denitrification

Denitrification is the biologically mediated transformation of nitrate to nitrogen gas (Trudell et al., 1986). If oxygen is not present (anaerobic conditions), nitarte may undergo denitrification to nitrous oxide gas or reduction to ammonia (Figure 55). Denitrification requires the absence of oxygen and proceeds most rapidly at the temperature range of 20°C - 35°C and neutral to slightly alkaline pH. Denitrification also requires organic carbon food source for bacteria to metabolize. Denitrification is delieved to be preferred over reduction except in organic rich soil. Nitrification process can be represented by the following reaction:

$$4\ NO_3^- + 5/6\ (C_6H_{12}O_6) + 4\ H^+ \text{ --------> } 2\ N_2 + 5\ CO_2 + 7\ H_2O \quad (7)$$

Denitrification is not an equilibrium process. However, it is irreversible because of the absence of suitable catalyst for the reverse reaction.

From the water quality viewpoint, denitrification is a desirable process, whereas increased concentration of dissolved N_2 and N_2O are not determinetal to drinking water. In contrast, nitrate at concentration above

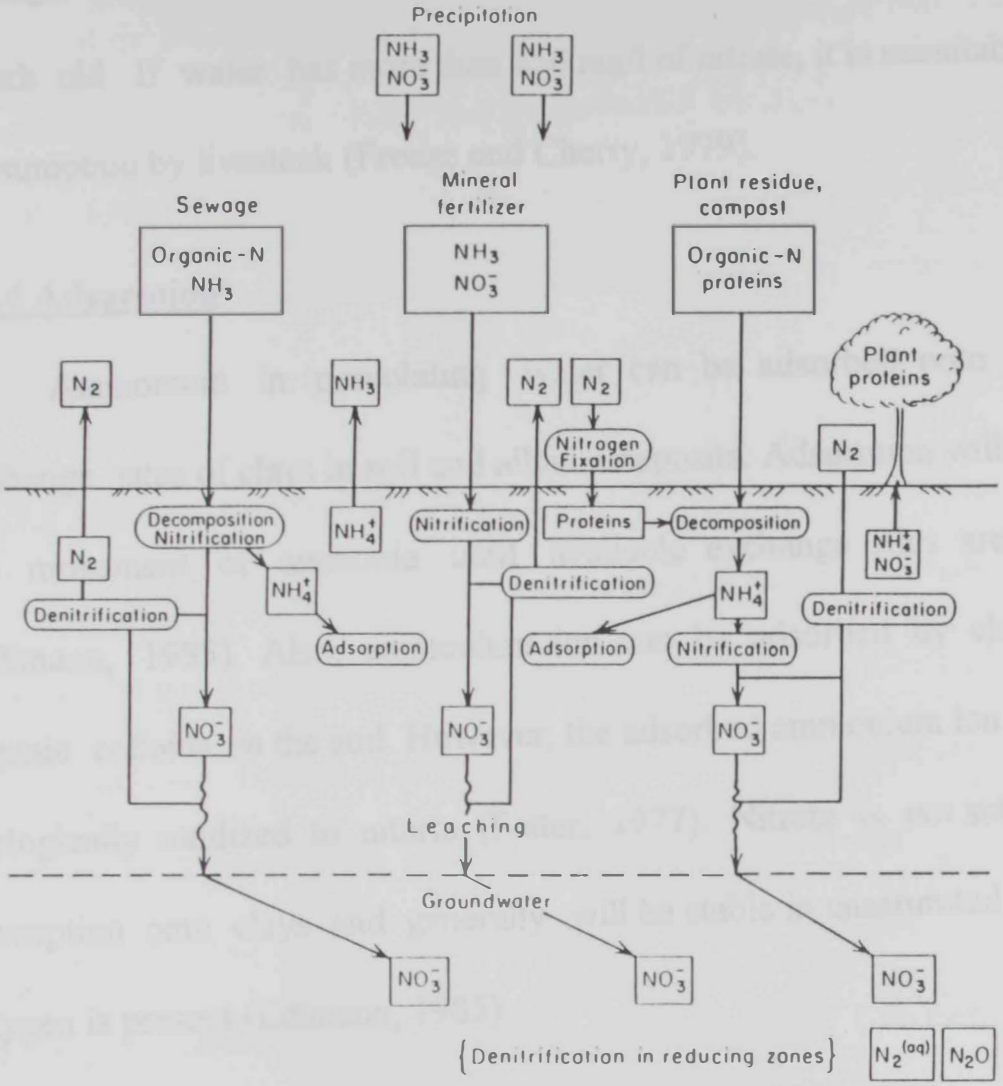

Figure 55. Sources and pathways of nitrogen in the subsurface environments (Freeze and Cherry, 1979).

45 mg/l renders water unfit for consumption by human infants under 6 month old. If water has more than 450 mg/l of nitrate, it is unsuitable for consumption by livestock (Freeze and Cherry, 1979).

4.2.4 Adsorption

Ammonium in percolating water can be adsorbed onto cation exchange sites of clays in soil and alluvial deposits. Adsorption will retard the movement of ammonia until available exchange sites are filled (Edlmann, 1985). Also, ammonium ion can ba adsorbed by clay and organic colloids in the soil. However, the adsorbed ammonium ion can be biologically oxidized to nitarte (Fetter, 1977). Nitrate is not subject to adsorption onto clays and generally will be stable in unsaturated zone if oxygen is present (Edlmann, 1985).

4.3 Sources of Nitrates in Groundwater

Nitrogen is one of the most abundant elements not only in the atmosphere (78% by volume of dry air) but also in the crust of the earth and hydrosphere. In rock and water, nitrogen is less abundant than carbon and oxygen. Widely variable amounts nitrogen occur in atmosphere and lithosphere.

The soil appears to be the great natural factory of nitrate and nitrogen, the active agent being bacteria. Most of nitrogen present in the

bodies of plant and animals ultimately forms ammonia. The ammonia released is then oxidized in to stages as the bacterium *Nitrosomanas* converts ammonia to nitrite and *Nitrobacter* oxidizes nitrite to nitrate (Feth, 1966). The sources of nitrogen compounds found in water are the atmosphere, geologic sources, agricultural sources, in addition other to miscellaneous sources.

4.3.1 Atmospheric Sources

Atmospheric aerosol is a worldwide layer occurs at altitude between 15 and 25 km above the earth as large particles consist entirely of sulphate and ammonia. Oxides of nitrogen are also present in the atmosphere from a range of sources both natural and industrial. Nitrogan can be oxidized during lightening discharges. In addition, oxides of nitrogen are formed during the combustion of a number of fossil fuels, (oil, gas and coal), motor exhausts and factories.

4.3.2 Geologic Sources

Geologic sources of nitrate include soil, cave deposits, organic rich shale and organic nitrogen compounds. Wnogradsky (1890) demostrated that nitrate is synthesized from nitrogenous compounds in soil and water through many chemical reactions. He also explained that the process of nitrification by: (a) the mineralization of organic nitrogen to yield

ammonium, (b) oxidation of ammonium ion to nitrite and (c) oxidation of nitrite to nitrate.

4.3.3 Agricultural Sources

Agricultural sources of nitrogen in soil originate mainly through the bacterial activity. Legume fix nitrogen at a rate of 40 to 200 Ib/acre/year. A value of 20 to 40 Ib/acre/year has been reported as the work of areobic bacterium, *Clostridium*, the aerobe *Azobacter* and blue-green algae. Photochemical fixation and adsorption of ammonia air by soil and plants may also add nitrogen to the soil. The highly soluble fertilizers, drainage water, barnyard, soil effluent and farm industry waste represent additional sources of nitrogen in soil. The use of fertilizers became indispensible to maintain the agricultural production and to increase it. Figure 56 shows the distribution of farms in Al Oha area as in 1993, traced from a Landsat satellite image scale 1:100,000. A proportion of the nitrogen fertilizers was taken up by the crop but excess would be available for leaching from the soil and into the groundwater. The rate of nitrate leaching from soil depends on a wide variety of factors.

The main chemical fertilizers used in agriculture are listed in Table 4. Table 5 shows the fate of nitrate fertilizers when applied to soil with good crop cover.

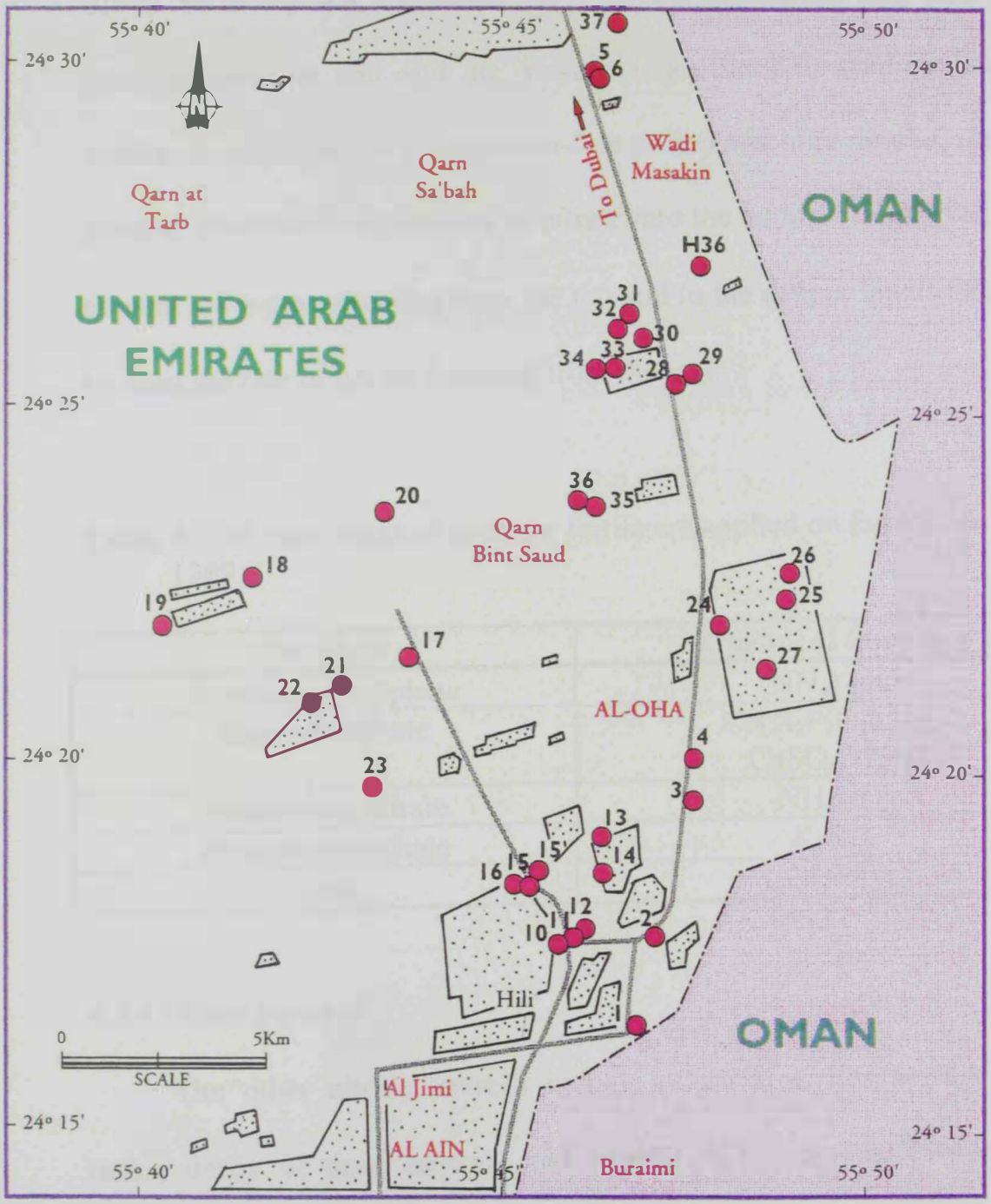

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Figure 56. Distribution of farms in Al Oha area as in 1993, traced from a Landsat satellite image scale 1:100,000.

Nitrate like all soluble ions, moves in the soil water and under plant cover. Root uptake, combined with evaporation of water and temperature gradient between soil and air, results in a general upward movement of nitrate. In contrast, in a vegetation-free period and high rainfall, there is a general downward movement of nitrate into the aquifer. In general, as the amount of water draining from the top soil to the deeper layers increases, so does the rate of nitrate leaching from the soil.

Table 4. The main types of nitrogen fertilizers applied on farm lands (ESG, 1989).

Fertilizer	Chemical Pormual
Ammonium sulphate	$(NN_4)_2SO_4$
Superphosphate	$Ca(H_2P_2O_2).H_2O$ $CaSO_4.2H_2O$
Ammonium nitrate	NH_4NO_3
Potassium sulphate	K_2SO_4
Urea	$CO(NH_2)_2$

4.3.4 Other Sources

The other nitrate sources include industrial wastes, sewage, septic tanks, decay of dead animals and vegetal matter and sanitary landfills. Nitrate is the end product of sewage disposal and result from microbial breakdown of organic nitrogen.

Table 5. The rate of administered nitrogen fertilizers applied to crops (Furrer, 1986).

Fertilizer consumption	**Percent (%)**
Taken up by crop plants	50-75
Bound as organic nitrogen in the soil	5-25
Bacterial breakdown to nitrogen gas	2-20
Leached into the subsoil	2-10

Because the average groundwater depth in Al Oha area is 30 m (Figure 7) and the mean annual rainfall does not exceed 100 mm, low nitrate ion (NO_3^-) concentrations were measured in groundwater collected from Al Oha area in March 1996 (Figure 35). The application of modern irrigation technologies in addition to the limited groundwater recharge does not permit effective nitrate leaching from the soil zone into groundwater within the study area.

CHAPTER VI

WATER QUALITY

CHAPTER VI

WATER QUALITY

Water quality determines its suitability for different uses. The following discussion intends to evaluate the suitability of groundwater in the Quaternary aquifer at Al Oha area for domestic and agricultural purposes.

The suitability of groundwater for a particular purpose depends on specific quality criteria. Quality limits of water supplies for drinking, irrigation and industrial uses apply to groundwater because of its extensive development for these purposes (Todd, 1980).

6.1 Domestic Uses

Usually, water applied for domestic purposes has certain standard specifications as regards to its physical, chemical and biological properties. These standards are intended primarily to protect human health. Tables 6 and 7 illustrate comparisons between Al Ain and Al Oha groundwater and the WHO (1984) and the GCC (1993) standards for drinking water.

Table 6. Comparison between Al Ain groundwater (February, 1995) with WHO (1971) and GCC Standards for drinking water.

Parameter	Al Ain 1995			WHO (1984)	GCC (1993)
	Maximum	Minimum	Mean	Guideline	Max. level
pH	8.2	6.9	7.4	6.5-8.5	6.5-8.5
Temp. °C	36.9	35.2	36.2	--	--
TDS	8,737	347	3,031	1,000	100-1,000
EC	5,200	400	3,946	1,400	160-1,600
Hardness	602.5	31.5	185.3	500	500
Ca^{2+}	281.5	11	86.52	75-200	200
Mg^{2+}	321	19.5	98.76	30-150	30-150
Na^{+}	3,397.9	39	847.37	200	200
K^{+}	66.5	2.3	17.84	--	--
CO_3^{2-}	24	3	11.15	--	--
HCO_3^{-}	329.4	36.6	147.58	--	--
Cl^{-}	4,599.2	46.1	1,159.97	250	250
NO_3^{-}	47.32	0.00	10.73	10	10
SO_4^{2-}	493.7	57.6	628.54	200-400	400
SiO_2	9.35	0.00	2.58	--	--
F^{-}	10.59	0.66	6.28	1.50	0.6-1.7
Fe	1.54	0.03	0.16	0.3-1.0	0.30
B	0.37	0.00	0.10	--	--
Zn	0.94	0.00	0.061	5.00	5.00
Ni	0.52	0.04	0.30	--	--
Cu	0.08	0.00	0.028	1.0-1.5	1.0
Co	0.03	0.00	0.004	--	--
Sr	3.21	0.88	2.27	--	--
Ba	0.13	0.00	0.036	--	--
Pb	0.34	0.00	0.12	0.05	0.05
Se	2.27	0.00	0.44	0.01	0.01

Chemical analysis is in mg/l, and conductivity in μS/cm. Averages are calculated for the total number of the samples and N.D. are replaced by zeros.

Table 7. Comparison between Al Oha groundwater (March, 1996) with WHO (1971) and GCC Standards for drinking water.

Parameter	Al Oha 1996			WHO (1984)	GCC (1993)
	Maximum	Minimum	Mean	Guideline	Max. level
pH	8.58	7.7	8.26	6.5-8.5	6.5-8.5
Temp. °C	36.9	35.2	36.2	--	--
TDS	6,144	525	1,848	1,000	100-1,000
EC	9,600	820	2,887	1,400	160-1,600
Hardness	476.2	47.6	164	500	500
Ca^{2+}	224	11	62	75-200	200
Mg^{2+}	243	38	230	30-150	30-150
Na^{+}	1,458	77	357	200	200
K^{+}	144	22	72	--	--
CO_3^{2-}	72	5	17	--	--
HCO_3^{-}	374	118	234	--	--
Cl^{-}	2,556	482	588	250	250
NO_3^{-}	39	89	8.0	10	10
SO_4^{2-}	1,295	1.13	431	200-400	400
SiO_2	17.5	2.1	1.13	--	--
F^{-}	4.64	0.27	0.07	1.50	0.6-1.7
Fe	0.33	0.00	0.07	0.3-1.0	0.30
B	0.37	0.00	0.10	--	--
Zn	2.18	0.00	0.20	5.00	5.00
Ni	0.52	0.04	0.30	--	--
Cu	0.23	0.00	0.08	1.0-1.5	1.0
Co	0.12	0.00	0.039	--	--
Sr	16.35	0.75	3.68	--	--
Ba	0.14	0.00	0.043	--	--
Cr	0.18	0.00	0.054	0.05	0.05
Se	2.27	0.00	0.44	0.01	0.01

Chemical analysis is in mg/l, and conductivity in µS/cm. Averages are calculated for the total number of the samples and N.D. are replaced by zeros.

6.1.1 Water Types

Based on the TDS contents in groundwater, the study area can be subdivided into three parts. The esatern part, including Al Hayer, Al Oha and Al Jaww plain, has TDS contents below 1,500 mg/l and its water is fresh and drinkable. Al Ain Water Factory is located in the southeastern corner of this part. The Middle part, including Qarn Bint Saud and Al Saad areas, has brackish water (TDS contents varies between 1,500 and 5,000 mg/l) which needs treatment prior use for domestic purposes. The third part includes Suweyhan area and its water is saline and unsuitable for most domestic purposes (TDS >5000 mg/l).

According to the TDS content, the Quaternary aquifer in the Al Ain area can be divided into an eastern fresh-water region (TDS is <1,500 mg/l), a central brackish-water region (TDS varies between 1,500 and 5,000 mg/l) and a western saline-water region (TDS is > 5,000 mg/l). Al Oha area is located within the fresh-water region (Figure 57).

6.1.2 Water Hardness

Total water hardness is defined as the sum of Ca^{2+} and Mg^{2+} concentrations expressed as mg/l of $CaCO_3$ (Bouwer, 1978). Water classification according to hardness is given in Table 8.

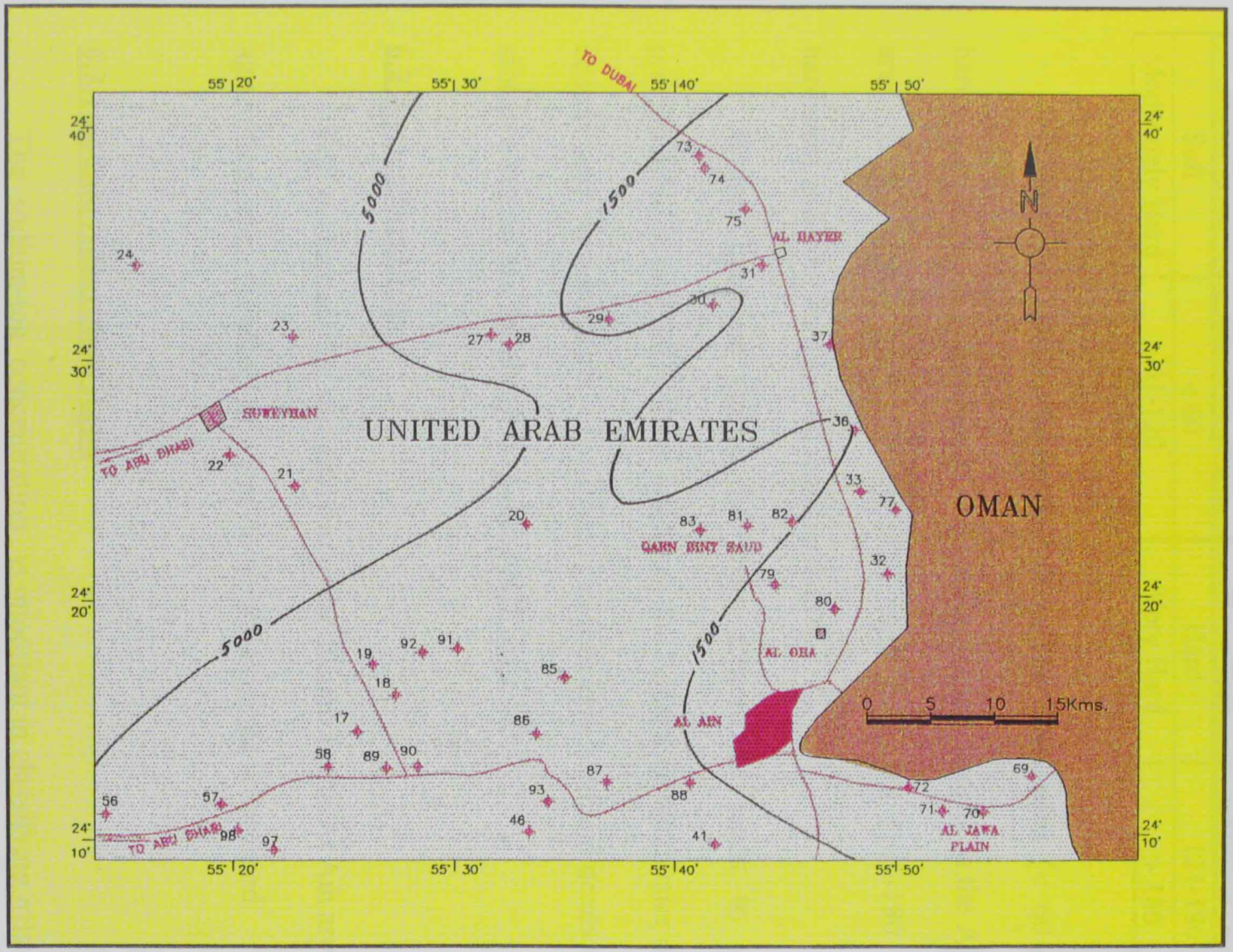

Figure 57. Classification of Al Ain groundwater into fresh, brackish and saline, according to its TDS contents, February 1995.

Table 8. Classification of water according to its hardness expressed in mg/l of $CaCO_3$ (Hem, 1970).

Water type	Hardness (mg/l)	Water type	Hardness (mg/l)
Soft	< 60	Hard	121-180
Moderately Hard	61-120	Very Hard	> 180

Except for the northeastern part of the study area (< 60 mg/l hardness), most of groundwater in the Quaternary aquifer in the Al Ain area is moderately hard (61-120 mg/l hardness), hard (121-180 mg/l hardness) and very hard (> 180 mg/l hardness).

Water hardness stops the soap action and leads to scale precipitation in tubes of lundary machines and boilers. Groundwater of the central and western parts of Al Ain is hard to very hard and needs to be sfotened before use for domestic purposes (Figure 58).

6.2 Agricultural Uses

For evaluation the suitability of groundwater in the Al Ain area for agricultural uses, the effect of water on plants and soils is assessed.

6.2.1 Sodiun Adsorption Ratio

The sodium-ion concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. The Sodium Adsorption Ratio (SAR) is defined by the following equation

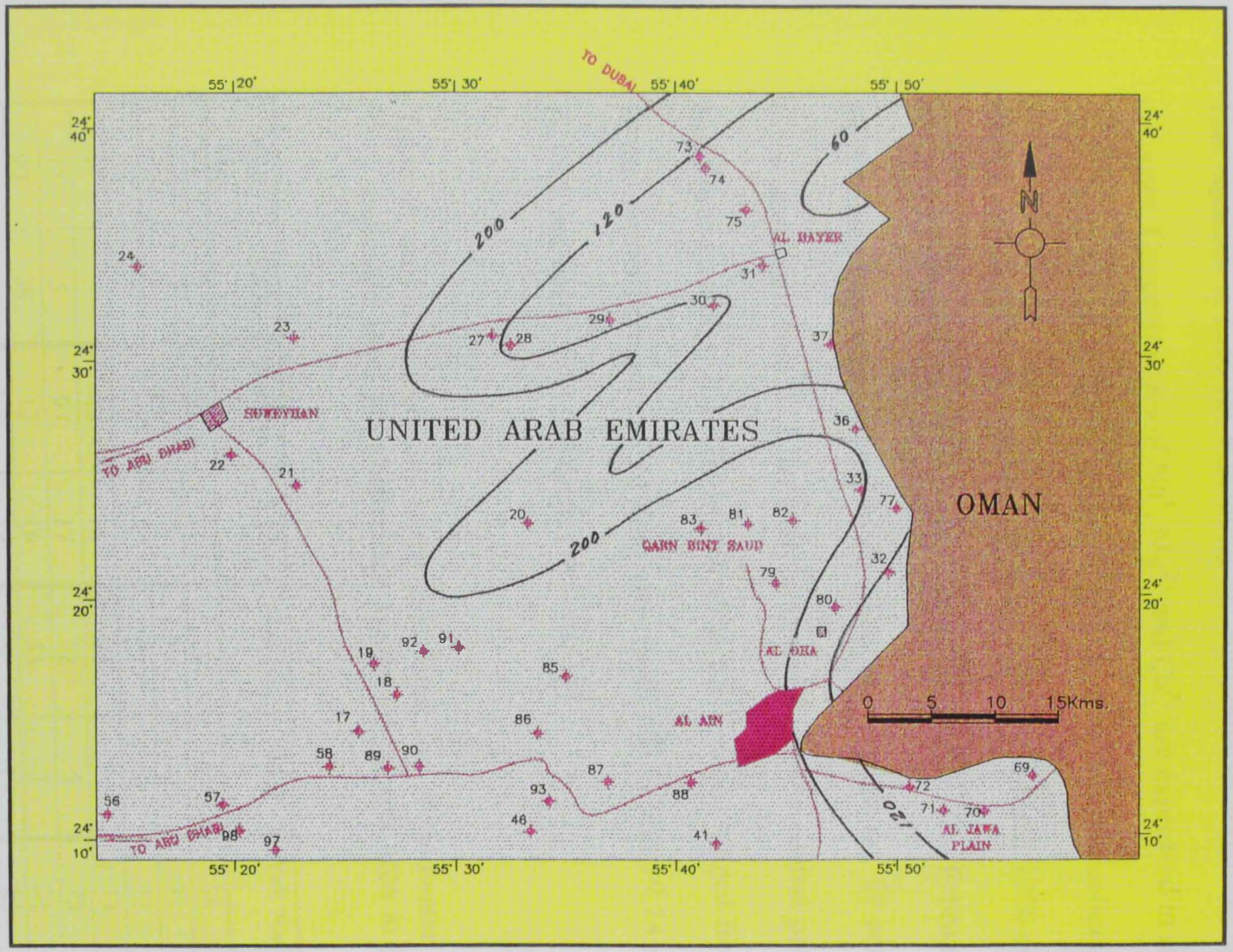

Figure 58. Classification of Al Ain groundwater into soft, moderately hard, hard and very hard, February 1995.

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \qquad (8)$$

This equation is used for evaluating the suitability of water for irrigation purposes. Concentrations of Na^{+}, Mg^{2+} and Ca^{2+} are expressed in meq/l.

The calculated SAR values for groundwater samples collected from Al Ain and Al Oha areas during February 1995 and March 1996 are listed in Tables 9 and 10 and shown on Figures 59 and 60. The February 1995 SAR values ranged between 2 in Al Jaww plain (wells no. 69 and 71) in the southeastern corner of the study area and 47 in the central part of the study area (well no. 20). The March 1996 SAR values ranged from 2.22 in the northeastern part of Al Oha area (well no. 5) and 19.14 south of Al Oha and north of Al Hili areas (well no. 13).

Table 9. Sodium adsorption ratios calculated for groundwater samples collected from the Quaternary aquifer of Al Ain area in February 1995.

Well No.	SAR	Well No.	SAR	Well No.	SAR	Well No	SAR
74	3	22	37	23	43	58	16
31	5	69	2	24	32	71	2
36	5	70	5	27	41	72	4
37	5	46	16	28	10	73	9
77	5	97	17	32	5	75	5
90	38	17	16	33	5	21	45
19	28	18	14	56	17	20	47

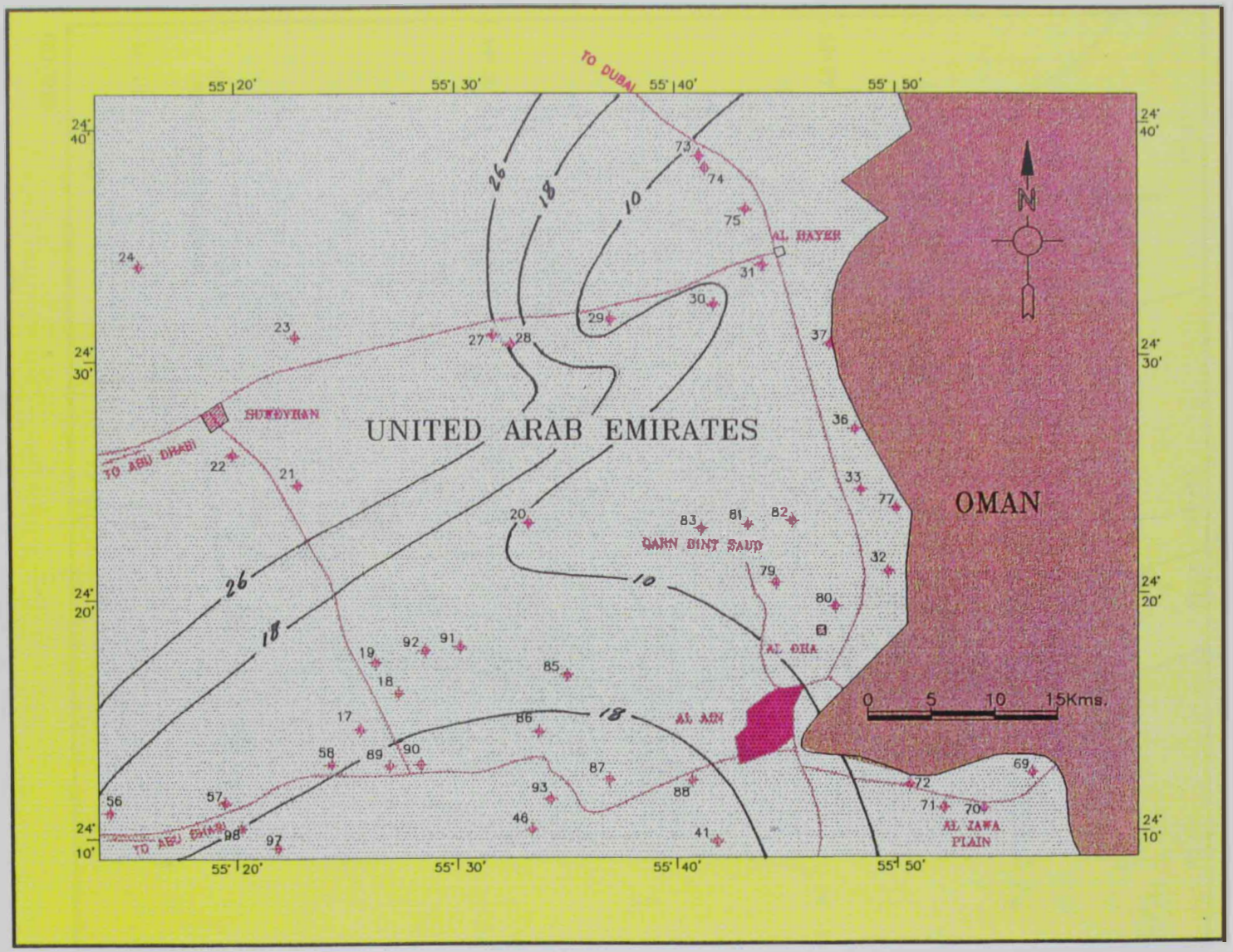

Figure 59. Iso-SAR contour map of groundwater in the Quaternary aquifer of Al Ain area February 1995.

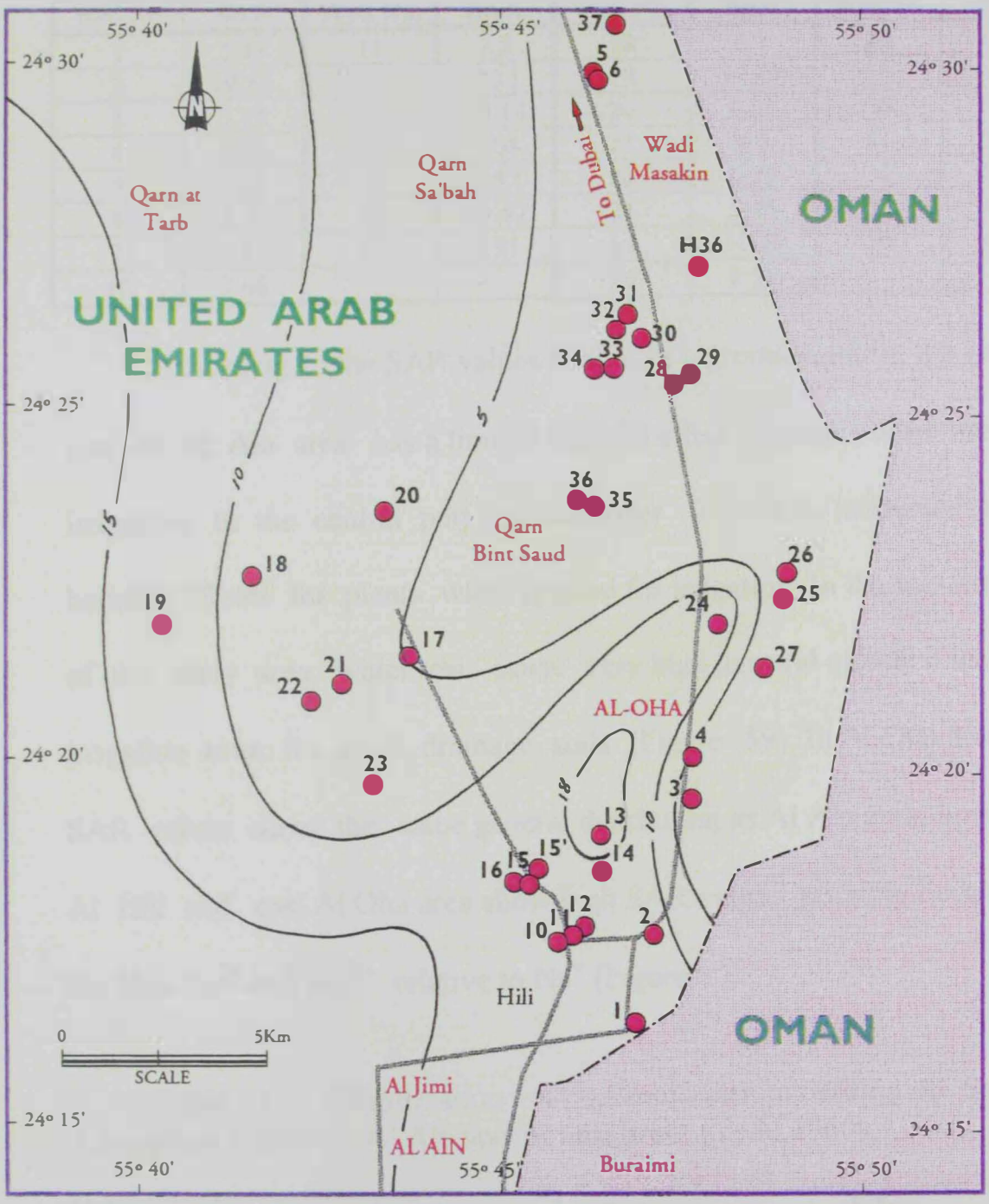

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Figure 60. Iso-SAR contour map of groundwater in the Quaternary aquifer of Al Oha area March 1996.

Table 10. Sodium adsorption ratios calculated for groundwater samples collected from the Quaternary aquifer of Al Oha area in March 1996.

Well No.	SAR	Well No.	SAR	Well No.	SAR	Well No.	SAR
1	5.33	11	7.5	18	6.4	28	4.52
2	10.45	12	7.33	19	14.01	29	4.23
3	3.94	13	19.14	20	4.61	30	5.73
4	3.04	14	5.08	21	3.5	31	3.78
5	2.22	15	5.87	22	4.76	32	5.29
6	2.52	16	13.87	23	5.46	33	4.84
7	1.95	17	4.91	24	11.26	35	4.08
10	7.66			26	2.55		

According to the SAR values (Table 11), groundwater in the eastern part of Al Ain area has a limited harmful effect on plants when used for irrigation. In the central part, groundwater can cause moderate to high harmful effects for plants when applied for irrigation. In the western part of the study area, water can cause very high harmful effects if used for irrigation even for good drainage soils (Figure 59). In Al Oha area, the SAR values show the same general distrbution as Al Ain area, however, Al Hili and east Al Oha area show high SAR values, possibly because of the high Ca^{2+} and Mg^{2+} relative to Na^{+} (Figure 60).

Table 11. Classification of groundwater according to Sodium Adsorption Ratios for Al Ain and Al Oha areas (Todd,1980).

SAR	Effect	SAR	Effect
< 10	Limited harmful effect	18-26	High harmful effect
10-18	Moderate harmful effect	> 26	Very high harmful effect

6.2.2 Irrigation Water

In addition to other criteria, the suitability of groundwater for irrigation can be based on salinity. In Al Ain area, the low-salinity groundwater (< 500 mg/l) in the northeastern part can be used for irrigating all kinds of crops (Figure 61). Water at Al Hayer, Al Oha and Al Jaww plain areas are suitable for irrigation of several crops (TDS ranges from 500 to 1,000 mg/l). Westwards, water salinity gets higher and its suitability for irrigation becomes limited to salt-tolerant crops. Around Suweyhan, groundwater is very harmful for irrigation of traditional crops (TDS > 5,000 mg/l).

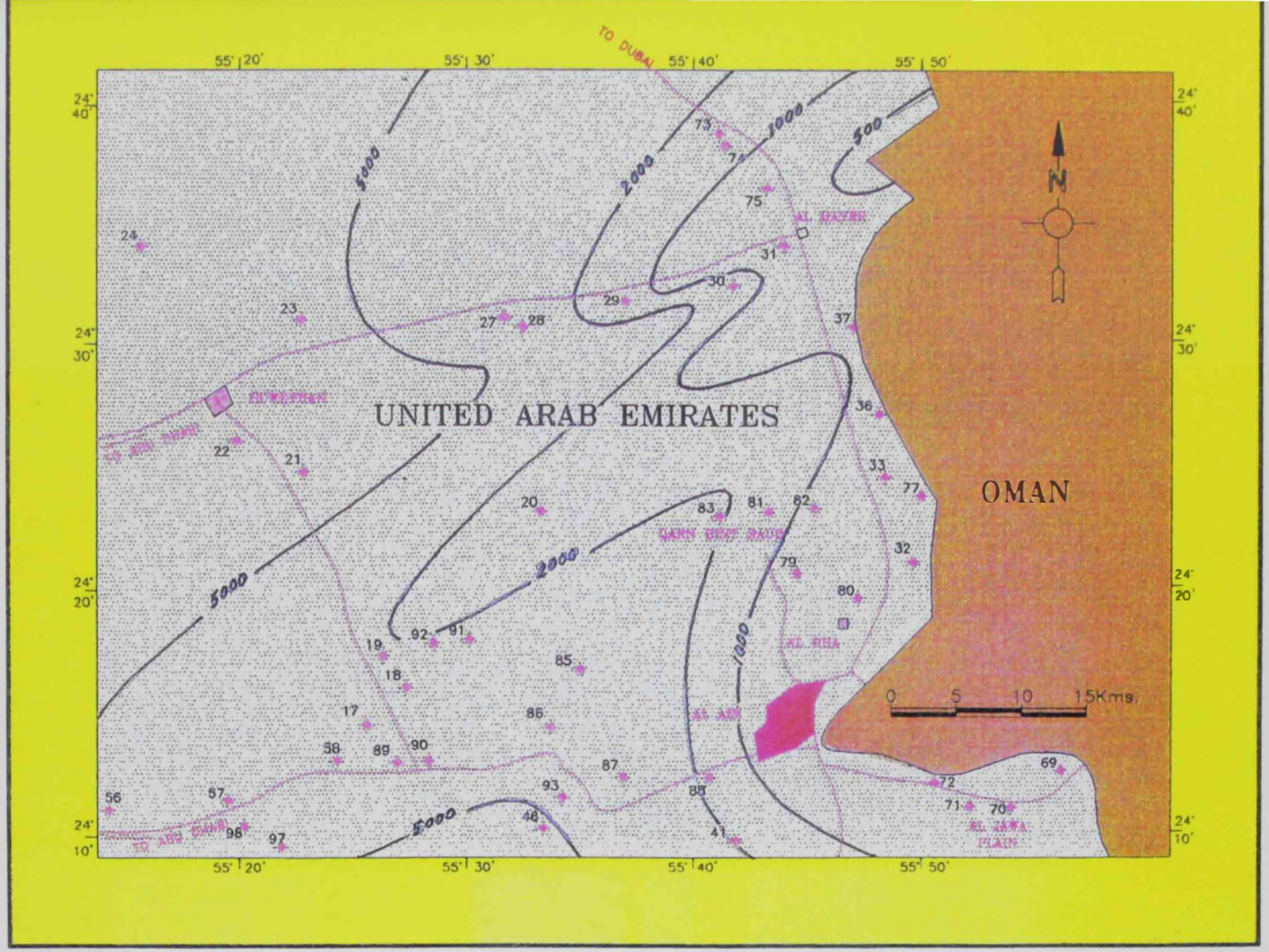

Figure 61. Classification of groundwater of AL Ain area for irrigation of different Kinds of crops , according to salinity

CHAPTER VII

CONCLUSIONS

CHAPTER VII

CONCLUSIONS

1. The location of Al Ain and Al Oha areas close to the Oman mountains has a clear influence on quantity, chemistry and quality of their groundwater. The Quaternary alluvial aquifer in both areas receives 15 million cubic meters of low-salinity, good-quality water as an annual recharge.
2. The low dissolution and reactivity of the gravels and sands forming the Quaternary aquifer in Al Ain and Al Oha areas help maintaining good-quality groundwater in both areas.
3. The mean annual values of air temperature, relative humidity, pan evaporation and rainfall in Al Oha area are 27.5°C, 50%, 3650 mm and 100 m, respectively.
4. The depth to groundwater in Al Ain and Al Oha areas are 90 and 30 m, respectively. The hydraulic head changes from 300 m above sea level (asl) east of Al Oha area to 150 m asl west of Al Ain town. Excessive groundwater pumping has created two cones of depression centered west of Al Ain and east of Suweyhan areas.

5. The average transmissivity (T) of the Quaternary alluvial aquifer in Al Ain area and Al Oha areas is 5200 m^2/day and the average storativity (S) is 5×10^{-4}.

6. The TDS contents in groundwater of Al Oha area in March 1996 ranged from about 500 mg/l in the northeast to 6,000 mg/l in the southeast. The high groundwater salinity within Al Ain city indicates the effect of heavy pumping. The TDS contents in Al Oha groundwater exceeds the WHO recommended limit for drinking water in several wells, especially those in the western part.

7. The sequence of cation dominance in groundwater of the Quaternary aquifer in Al Ain area in February 1995 has the order: $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ in the eastern part and $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ in the western part. In March 1996, the order of cation dominance in groundwater of Al Oha area was $Na^+ > Mg^{2+} > Ca^{2+} > K^+$. Iso-concentration contour maps shows a general increase in the amounts of all cations from east to west; in the direction of groundwater flow. Local increases are associated with heavy groundwater pumping or downward movement of relatively high-salinity irrigation water into the aquifer.

8. The sequence of anions dominance in groundwater of Al Ain area in February 1995 has the order: $HCO_3^- > Cl^- > SO_4^{2-} > CO_3^{2-}$ in the eastern part and $Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$ in the western part. In March 1996, the

anion dominance in groundwater of Al Oha was: HCO_3^-> Cl^-> SO_4^{2-} >CO_3^{2-} in the eastern part and Cl^-> SO_4^{2-}> HCO_3^-> CO_3^{2-} in the western part. Except for HCO_3^-, concentrations of all anions increases from east to west; in the direction of groundwater flow.

9. Except of one sample collected from the Well no. 57, along Al Ain-Abu Dhabi road, nitrate ion (NO_3^-) content in groundwater of Al Ain and Al Oha areas are below the WHO recommended limit for drinking water. Because the average groundwater depth in Al Oha area is 30 m and the mean annual rainfall does not exceed 100 mm, low nitrate ion (NO_3^-) concentrations were measured in groundwater Al Ain and Al Oha areas during February 1996-March 1996 period. The application of modern irrigation technologies in addition to the limited groundwater recharge does not permit effective leaching of nitrate ion (NO_3^-) from the soil zone into groundwater underneath the study area.

10. Phosphate concentration of groundwater samples collected from the Quaternary aquifer in the Al Ain area in February 1995 ranged from 0.6 mg/l in the western part to 1 mg/l in the northeast. Despite the fact that phosphate fertilizers are equally in use as the nitrates, phosphate concentrations in groundwater are much lower because of their attenuation in the soil zone.

11. Concentrations of barium (Ba), chromium (Cr), Copper (Cu), iron (Fe), lead (Pb), manganese (Mn), zinc (Zn), fluoride (F) and strontium (Sr) were measured in groundwater samples collected from the study area in February 1995 and March 1996. Contents of these trace constituents are below WHO recommended limits for drinking water in most wells. However, some wells with contents above the WHO limits exist in the western part of the study area or close to urban centers which represent artificial sources of these metals.

12. Comparison of the water quality parameters of the WHO and the GCC with those of groundwater in Al Ain and Al Oha area indicate that water in both areas, especially in the eastern part, meets the recommended limits for drinking water.

13. According to the TDS content, the Quaternary aquifer in the Al Ain area can be divided into an eastern fresh-water region (TDS is <1,500 mg/l), a central brackish-water region (TDS varies between 1,500 and 5,000 mg/l) and a western saline-water region (TDS is > 5,000 mg/l). Al Oha area is located within the fresh-water region.

14. Except for the northeastern part of the study area (< 60 mg/l hardness), most of groundwater in the Quaternary aquifer in the Al Ain area is moderately hard (61-120 mg/l hardness), hard (121-180 mg/l hardness) and very hard (> 180 mg/l hardness).

15. According to the SAR values, groundwater in the eastern part of Al Ain area has a limited harmful effect on plants when used for irrigation. In the central part, groundwater can cause moderate to high harmful effects for plants when applied for irrigation. In the western part of the study area, water can cause very high harmful effects if used for irrigation even for good drainage soils. In Al Oha area, the SAR values show the same general distrbution as Al Ain area, however, Al Hili and east Al Oha area show high SAR values, possibly because of the high Ca^{2+} and Mg^{2+} relative to Na^{+}.

16. In Al Ain area, the low-salinity groundwater (< 500 mg/l) in the northeastern part can be used for irrigating all kinds of crops. Water at Al Hayer, Al Oha and Al Jaww plain areas are suitable for irrigation of several crops (TDS ranges from 500 to 1,000 mg/l). Westwards, water salinity gets higher and its suitability for irrigation becomes limited to salt-tolerant crops. Around Suweyhan, groundwater is very harmful for irrigation of traditional crops (TDS > 5,000 mg/l).

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APPENDICES

APPENDIX A

Results of chemical analysis of groundwater samples collected from the Quaternary aquifer of Al Ain area in February 1995

Ser. No.	Well No.	EC (ms)	pH	TDS	Units	Ca++	Mg++	Na+	K+	Sum. Cat.	CO3–	HCO3-	SO4–	Cl-	Sum. ani.
1	74	3 5	7 6	1982.7	ppm	102	173 9	340.3	12.9	34.5	9	122	523.2	699 4	32.9
					epm	5.1	14.3	14 8	0.3		0.3	2	10.9	19.7	
					e%	14 7	41 4	42.9	1		0.9	6.1	33.1	59.9	
2	31	0 6	8	478 8	ppm	22.4	29.2	80.5	4.3	7.1	15	128.1	124.8	74.5	7.3
					epm	1 1	2.4	3.5	0.1		0.5	2.1	2.6	2.1	
					e%	15.7	33.7	49 1	1.5		6.8	28.8	35.6	28.8	
3	36	2	7 8	1238.3	ppm	38 8	77 8	259.8	5.9	19.8	9	122	398.4	326.6	19 8
					epm	1 9	6 4	11 3	0.2		0.3	2	8.3	9.2	
					e%	9.8	32.3	57.1	0.8		1.5	10.1	41.9	46.5	
4	37	0 8	8	549.1	ppm	22.4	31 6	101 2	5.1	8.2	9	122	158.4	99 4	8 4
					epm	1 1	2.6	4 4	0.1		0.3	2	3.3	2.8	
					e%	13 6	31.5	53 4	1 6		3.6	23.8	39.3	33 4	
5	77	2 7	7 8	1618.7	ppm	30.6	113.1	360.9	10.6	26.8	12	176.9	417.6	497	26
					epm	1.5	9.3	15 7	0.3		0.4	2.9	8.7	14	
					e%	5.7	34 7	58.6	1		1.5	11.1	33 4	53.9	
6	79	4 7	8	2593.5	ppm	14 3	119.2	719.6	19.5	42.3	9	329.4	456	926.5	41 3
					epm	0.7	9 8	31.3	0.5		0.3	5.4	9.5	26.1	
					e%	1.7	23.2	74	1.2		0.7	13.1	23	63.2	
7	80	5 2	8	3006 2	ppm	22.4	135	839.1	24.2	49.3	21	305	633.6	1025.9	47 8
					epm	1 1	11 1	36.5	0.6		0.7	5	13.2	28.9	
					e%	2.3	22.5	74	1.3		1.5	10.5	27.6	60.5	
8	81	1 5	8.2	1047.9	ppm	32.6	55.9	220.7	7.8	16	21	183	278.4	248.5	16.5
					epm	1.6	4 6	9.6	0.2		0.7	3	5.8	7	
					e%	10 2	28.7	59.9	1.2		4.2	18.2	35.1	42.5	
9	82	6 4	7	3775 8	ppm	81 6	290 6	839.1	16.8	64.9	15	301.9	782.4	1448.4	62.6
					epm	4 1	23 9	36 5	0 4		0.5	4.9	16.3	40.8	
					e%	6 3	36.8	56.2	0.7		0.8	7.9	26	65.3	

Ser. No.	Well No.	EC (ms)	pH	TDS	Units	Ca++	Mg++	Na+	K+	Sum. Cat.	CO3–	HCO3-	SO4–	Cl-	Sum. ani.
10	83	1.5	8	1039.4	ppm	11	36.5	280.5	7.8	16	15	262.3	192	234.3	15.4
					epm	0 5	3	12.2	0.2		0.5	4.3	4	6.6	
					e%	3.4	18 8	76 5	1.3		3.2	27.9	25.9	42.9	
11	85	5	7 8	2809 3	ppm	97 9	115 5	742.6	11 7	47	6	115.9	619.2	1100.5	46
					epm	4 9	9.5	32.3	0.3		0.2	1.9	12.9	31	
					e%	10 4	20 2	68.7	0.6		0.4	4.1	28	67.4	
12	86	2.9	8	1787.2	ppm	14 3	48 6	519.6	25 4	28	12	240.9	326.4	600	28 1
					epm	0 7	4	22.6	0.6		0.4	3.9	6.8	16.9	
					e%	2.6	14.3	80.8	2.3		1.4	14.1	24.2	60.3	
13	87	2	8	1237 7	ppm	14 3	59 6	301 2	18	19.2	9	173.8	278.4	383.4	19 8
					epm	0 7	4 9	13.1	0.5		0.3	2.8	5.8	10.8	
					e%	3.7	25.6	68.3	2.4		1.5	14.4	29.3	54.7	
14	89	6.1	7 8	3569 3	ppm	142 8	180	839.1	10.6	58.7	3	94.5	772.8	1526.5	60.8
					epm	7 1	14 8	36.5	0.3		0.1	1.5	16.1	43	
					e%	12.1	25.2	62.2	0.5		0.2	2.5	26.5	70.8	
15	90	6 5	6 9	3767	ppm	114.2	118	1101 2	19.5	63.8	12	109.8	868.8	1423.5	60 4
					epm	5 7	9 7	47 9	0 5		0.4	1.8	18.1	40.1	
					e%	8.9	15.2	75.1	0.8		0.7	3	29.9	66.4	
16	19	6 6	7.9	3484 3	ppm	89 8	66 9	1101.2	23.1	58.5	9	109.8	643.2	1441.3	56.1
					epm	4 5	5 5	47 9	0.6		0.3	1.8	13.4	40.6	
					e%	7.7	9 4	81.9	1		0.5	3.2	23.9	72.4	
17	21	10 1	7 7	5737.2	ppm	140.8	99 6	1800.1	18.4	94	3	112.8	1329.6	2232.9	92.6
					epm	7	8.2	78.3	0.5		0.1	1.8	27.7	63	
					e%	7.5	8.7	83.3	0.5		0.1	2	29.9	68	
18	22	11 4	8.1	6501 4	ppm	271.3	187.3	1846.1	21.1	109.8	3	94.5	1728	2350.1	103.9
					epm	13.5	15.4	80.3	0.5		0.1	1.5	36	66.3	
					e%	12.3	14	73.1	0.5		0.1	1.5	34.6	63.8	

Ser. No.	Well No.	EC (ms)	pH	TDS	Units	Ca++	Mg++	Na+	K+	Sum. Cat.	CO3--	HCO3-	SO4--	Cl-	Sum. ani.
19	29	1.3	7.8	817.3	ppm	24.5	34	200	10.6	13	6	115.9	192	234.3	12.7
					epm	1.2	2.8	8.7	0.3		0.2	1.9	4	6.6	
					e%	9.4	21.5	67	2.1		1.6	15	31.5	52	
20	92	10.5	7.8	6200.9	ppm	171.4	176.3	1859.9	14.1	104.3	9	100.7	1444.8	2424.7	100.4
					epm	8.6	14.5	80.9	0.4		0.3	1.7	30.1	68 4	
					e%	8.2	13.9	77.6	0.3		0.3	1.6	30	68.1	
21	30	7.7	7.4	4489.5	ppm	281.5	321	852.9	13.7	77.9	6	94.5	1070 4	1849.5	75
					epm	14	26.4	37.1	0 4		0.2	1.5	22.3	52.2	
					e%	18	33.9	47.6	0 4		0.3	2	29.2	68.5	
22	91	5.2	8	3104.2	ppm	212.2	114.3	680.5	23.8	50.2	15	106.8	1128	823.6	49
					epm	10.6	9.4	29.6	0.6		0.5	1.8	23.5	23.2	
					e%	21.1	18.7	59	1.2		1	3.6	48	47 4	
23	69	0.6	8.2	423.8	ppm	18.4	35.3	50.6	2.3	6.1	9	103.7	158.4	46.1	6.6
					epm	0.9	2.9	2.2	0.1		0.3	1.7	3.3	1.3	
					e%	15.1	47.7	36.2	1		4.5	25.8	50	19.7	
24	70	0.7	8	567.8	ppm	22.4	45	80.5	3.1	8.4	6	109.8	201.6	99 4	9
					epm	1.1	3.7	3.5	0.1		0.2	1.8	4.2	2.8	
					e%	13.3	44.1	41.7	0.9		2.2	20	46.6	31.1	
25	93	4	7.9	2403.6	ppm	83.6	98.5	620.7	14.9	39.7	12	97.6	475.2	1001.1	40.1
					epm	4.2	8.1	27	0 4		0.4	1.6	9.9	28.2	
					e%	10.5	20 4	68.1	1		1	4	24.7	70 4	
26	46	6.2	7.8	3628.3	ppm	191.8	165.4	839.1	18.8	60.2	9	73.2	580.8	1750.2	62.9
					epm	9.6	13.6	36.5	0.5		0.3	1.2	12.1	49 4	
					e%	15.9	22.6	60.7	0.8		0.5	1.9	19.2	78 4	
27	97	8	7 4	5021.9	ppm	275.4	227.4	1101.2	37.5	81.3	12	97.6	1968	1302.8	79.7
					epm	13.7	18.7	47.9	1		0 4	1.6	41	36.7	
					e%	16.9	23	58.9	1.2		0.5	2	51.4	46.1	

Ser. No.	Well No.	EC (ms)	pH	TDS	Units	Ca++	Mg++	Na+	K+	Sum. Cat.	CO3–	HCO3-	SO4–	Cl-	Sum. ani.
28	98	1.7	7.7	1045.6	ppm	32.6	29.2	280.5	8.2	16.4	9	143.3	312	230.8	15.7
					epm	1.6	2.4	12.2	0.2		0.3	2.3	6.5	6.5	
					e%	9.9	14.6	74.2	1.3		1.9	15	41.5	41.6	
29	41	8.9	7.5	5098.6	ppm	208.1	119.2	1446.1	23.8	83.7	3	36.6	720	2541.8	87.4
					epm	10.4	9.8	62.9	0.6		0.1	0.6	15	71.7	
					e%	12.4	11.7	75.2	0.7		0.1	0.7	17.2	82	
30	88			2676.9	ppm	126.5	143.5	620.7	16	45.5	21	115.9	532.8	1100.5	44.7
					epm	6.3	11.8	27	0.4		0.7	1.9	11.1	31	
					e%	13.9	25.9	59.3	0.9		1.6	4.2	24.8	69.4	
31	17	14.3	7.8	8737.7	ppm	128.3	189.7	2899	43	149.2	12	122	744.5	4599.2	147.6
					epm	6.4	15.6	126.1	1.1		0.4	2	15.5	129.7	
					e%	4.3	10.5	84.5	0.7		0.3	1.4	10.5	87.9	
32	18	2.8	7.9	1692.5	ppm	40.1	28	487.4	23.5	26.1	6	97.6	634	375.9	25.6
					epm	2	2.3	21.2	0.6		0.2	1.6	13.2	10.6	
					e%	7.7	8.8	81.2	2.3		0.8	6.2	51.6	41.4	
33	20	15.2	7.7	10325	ppm	222.4	104.6	3397.9	66.5	169.2	15	164.7	1935.6	4418.3	168.1
					epm	11.1	8.6	147.8	1.7		0.5	2.7	40.3	124.6	
					e%	6.6	5.1	87.4	1		0.3	1.6	24	74.1	
34	23	12.6	7.8	8402	ppm	98.2	131.3	2797.9	46.9	138.6	6	97.6	1493.7	3730.4	138.1
					epm	4.9	10.8	121.7	1.2		0.2	1.6	31.1	105.2	
					e%	3.5	7.8	87.8	0.9		0.1	1.2	22.5	76.2	
35	24	7.6	7.8	4748.8	ppm	90.2	58.4	1485.2	35.2	74.8	9	122	1349.6	1599.2	75.5
					epm	4.5	4.8	64.6	0.9		0.3	2	28.1	45.1	
					e%	6	6.4	86.4	1.2		0.4	2.6	37.2	59.7	
36	27	4.2	7.9	2911.7	ppm	12	19.5	1000.1	11.7	46	24	244	600.4	1000	45.5
					epm	0.6	1.6	43.5	0.3		0.8	4	12.5	28.2	
					e%	1.3	3.5	94.6	0.7		1.8	8.8	27.5	62	

Ser. No.	Well No.	EC (ms)	pH	TDS	Units	Ca++	Mg++	Na+	K+	Sum. Cat.	CO3--	HCO3-	SO4--	Cl-	Sum. ani.
37	28	6.5	7.8	4436.7	ppm	38.1	37.7	1498.9	23.5	70.8	18	207.4	811.7	1801.4	71.7
					epm	1.9	3.1	65.2	0.6		0.6	3.4	16.9	50.8	
					e%	2.7	4.4	92.1	0.8		0.8	4.7	23.6	70.9	
38	32	0.9	7.8	588.8	ppm	16	19.5	131	3.9	8.2	12	207.4	28.8	170.2	9.2
					epm	0.8	1.6	5.7	0.1		0.4	3.4	0.6	4.8	
					e%	9.7	19.6	69.5	1.2		4.3	37	6.5	52.2	
39	33	1.7	7.9	915.1	ppm	16	57.2	204.6	3.9	14.5	18	183	67.2	365.2	15.3
					epm	0.8	4.7	8.9	0.1		0.6	3	1.4	10.3	
					e%	5.5	32.4	61.4	0.7		3.9	19.6	9.1	67.3	
40	56	6.3	7.9	3950.3	ppm	56.1	49.9	1298.9	23.5	64	12	134.2	826.1	1549.6	63.5
					epm	2.8	4.1	56.5	0.6		0.4	2.2	17.2	43.7	
					e%	4.4	6.4	88.3	0.9		0.6	3.5	27.1	68.8	
41	57	6	7.8	3939.8	ppm	140.3	87.6	1066.7	31.3	61.4	9	103.7	1440.9	1060.3	61.9
					epm	7	7.2	46.4	0.8		0.3	1.7	30	29.9	
					e%	11.4	11.7	75.6	1.3		0.5	2.7	48.5	48.3	
42	58	5.3	7.7	2996.3	ppm	82.2	87.6	898.9	19.5	50.9	6	103.7	341	1457.4	50.1
					epm	4.1	7.2	39.1	0.5		0.2	1.7	7.1	41.1	
					e%	8.1	14.2	76.8	1		0.4	3.4	14.2	82	
43	71	0.4	7.7	347.1	ppm	18	28	39.1	3.9	5	6	134.2	57.6	60.3	5.3
					epm	0.9	2.3	1.7	0.1		0.2	2.2	1.2	1.7	
					e%	18	46	34	2		3.8	41.5	22.6	32.1	
44	72	1.1	7.6	778.3	ppm	36.1	45	149.4	3.9	12.1	6	140.3	177.7	219.9	12.4
					epm	1.8	3.7	6.5	0.1		0.2	2.3	3.7	6.2	
					e%	14.9	30.6	53.7	0.8		1.6	18.5	29.8	50	
45	73	2.9	7.8	2067.6	ppm	48.1	108.2	498.9	19.5	33.5	21	207.4	465.9	698.6	33.5
					epm	2.4	8.9	21.7	0.5		0.7	3.4	9.7	19.7	
					e%	7.2	26.6	64.8	1.5		2.1	10.1	29	58.8	
46	75	1.1	8.1	921.7	ppm	26.1	43.8	200	11.7	13.9	24	219.6	187.3	209.2	14.2
					epm	1.3	3.6	8.7	0.3		0.8	3.6	3.9	5.9	
					e%	9.4	25.9	62.6	2.2		5.6	25.4	27.5	41.5	

Ser. No.	Well No.	Sr	Cr	Fe	Zn	Pb	Cu	Co	Ba	Mn	F	NO3
1	17	9.30	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	18	7.75	0.05	0.03	0.00	0.00	0.03	0.00	0.00	0.00	1.64	4.08
3	20	8.11	0.05	0.15	0.00	0.08	0.00	0.00	0.00	0.00	9.35	7.54
4	23	11.20	0.21	0.07	0.00	0.39	0.03	0.01	0.03	0.00	6.22	13.91
5	24	10.59	0.07	0.13	0.00	0.23	0.00	0.00	0.00	0.00	4.74	5.46
6	27	2.98	0.10	0.04	0.00	0.25	0.00	0.00	0.00	0.00	2.03	6.06
7	28	7.06	0.09	0.04	0.00	0.01	0.00	0.03	0.04	0.00	3.55	18.25
8	32	1.37	0.00	1.54	0.94	0.26	0.05	0.00	0.12	0.00	0.67	1.71
9	33	2.30	0.00	0.04	0.00	0.00	0.01	0.00	0.13	0.00	0.88	3.18
10	56	6.79	0.14	0.06	0.02	0.07	0.04	0.02	0.02	0.00	4.74	4.70
11	57	8.57	0.09	0.07	0.02	0.04	0.02	0.00	0.04	0.00	3.66	47.32
12	58	10.16	0.01	0.07	0.00	0.06	0.05	0.00	0.05	0.00	0.00	42.50
13	71	6.61	0.05	0.14	0.00	0.03	0.05	0.00	0.03	0.00	0.09	1.22
14	72	0.66	0.01	0.06	0.00	0.02	0.00	0.01	0.10	0.00	1.41	1.61
15	73	5.26	0.06	0.04	0.00	0.03	0.08	0.00	0.02	0.00	1.70	9.18
16	75	1.88	0.04	0.04	0.00	0.03	0.08	0.00	0.00	0.00	0.71	5.09

APPENDIX B

Results of chemical analysis of groundwater samples collected from the Quaternary aquifer of Al Oha area in March 1996

Ser. No.	Well No.	EC	pH	TDS	Untis	Ca++	Mg++	Na+	K+	Sum Cat.	CO3–	HCO3-	SO4–	Cl-	Sum Ani.
1	1	2460	8.14	1574	ppm	69.4	79.2	274.9	52.1		7.2	145.8	227.7	527.3	
					epm	3.5	6.6	12	1.3	23.36	0.1	2.4	4.7	14.9	22.11
					epm%	14.9	28.3	51.2	5.7		0.5	10.8	21.5	67.2	
2	2	8120	8.14	5197	ppm	224.1	243.1	953.6	191		0	243	934.2	2075.4	
					epm	11.2	20.3	41.5	4.9	77.83	0	4	19.5	58.5	81.91
					epm%	14.4	26	53.3	6.3		0	4.9	23.8	71.4	
3	3	1360	8.37	870	ppm	46.1	51.8	165.1	31.3		10.8	232.1	110.5	247.3	
					epm	2.3	4.3	7.2	0.8	14.6	0.2	3.8	2.3	7	13.25
					epm%	15.8	29.6	49.2	5.5		1.4	28.7	17.4	52.6	
4	4	1770	8.39	1133	ppm	48.4	92	156.9	61.2		13.2	229.7	164.9	309.8	
					epm	2.4	7.8	6.8	1.6	18.48	0.2	3.8	3.4	8.7	16.15
					epm%	13.1	41.5	36.9	8.5		1.4	23.3	21.3	54	
5	5	820	8.45	525	ppm	19	44.3	77.9	28.2		12	150.7	75.5	114.5	
					epm	1	3.7	3.4	0.7	8.75	0.2	2.5	1.6	3.2	7.47
					epm%	10.9	42.2	38.1	8.3		2.7	33.1	21.1	43.2	
6	6	2330	8.09	1491	ppm	66.7	128	153.1	88.4		4.8	117.9	121.7	405.9	
					epm	3.3	10.7	6.7	2.3	22.92	0.1	1.9	2.5	14.2	18.77
					epm%	14.5	46.5	29	9.9		0.4	10.3	13.5	75.8	
7	7	950	8.32	608	ppm	37.3	48.3	76.7	30		8.4	158	124.8	124.1	
					epm	1.9	4	3.3	0.8	9.99	0.1	2.6	2.6	3.5	8.82
					epm%	18.7	40.3	33.4	7.7		1.6	29.4	29.5	39.6	
8	10	4100	8.28	2624	ppm	111.2	143.8	521.6	98		10.8	273.4	920.8	713.6	
					epm	5.6	12	22.6	2.5	42.73	0.2	4.5	19.2	20.1	43.94
					epm%	13	28	53.1	5.9		0.4	10.2	43.7	45.7	
9	11	4200	8.33	2688	ppm	111.7	153.5	523.2	109		16.7	317.2	873.6	721.5	
					epm	5.6	12.8	22.8	2.8	43.92	0.3	5.2	18.2	20.3	44
					epm%	12.7	29.1	61.6	6.4		0.6	11.8	41.4	46.2	

Ser. No.	Well No.	EC	pH	TDS	Untis	Ca++	Mg++	Na+	K+	Sum Cat.	CO3–	HCO3-	SO4–	Cl-	Sum Ani.
10	12	3960	8.29	2534	ppm	104 8	146 2	497 4	105 6		14.3	374.3	849.9	635.2	
					epm	5 2	12.2	21 6	2.7	41.76	0.2	6.1	17.7	17.9	41 97
					epm%	12.6	29.2	51.8	6.5		0.6	14.6	42.2	42.6	
11	13	9600	8.26	6144	ppm	153 5	171 1	1457 9	125.9		17.4	234.4	1295.6	2556.4	
					epm	7 7	14.3	63 4	3.2	88 55	0.3	3.8	27	72	103.13
					epm%	8.7	16.1	71.6	3.7		0.3	3.7	26.2	69.8	
12	14	2600	8 41	1664	ppm	76.6	111.3	299.3	76.7		15.5	263.7	504.2	447.3	
					epm	3 8	9.3	13	2	28.08	0.3	4.3	10.5	12.6	27 69
					epm%	13.6	33	46.3	7		0.9	15.6	37.9	45.5	
13	15	1500	8 54	960	ppm	26 6	45	215.3	29 1		13.2	250.3	188	191.6	
					epm	1 3	3.8	9.4	0.8	15.19	0.2	4.1	3.9	5 4	13 64
					epm%	8.8	24 7	61.6	4.9		1.6	30.1	28.7	39.6	
14	16	5060	8 33	3238	ppm	72 8	100 7	782.3	75.1		19.1	301.4	959.1	1115.7	
					epm	3 6	8 4	34	1.9	47.97	0.3	4.9	20	31.4	56 67
					epm%	7 6	17 5	70.9	4		0.6	8.7	35.3	55.5	
15	17	1170	8 41	749	ppm	25 9	38	168 8	24.3		13.2	240.6	115.3	153	
					epm	1.3	3.2	7.3	0.6	12.42	0.2	3.9	2.4	4 3	10.88
					epm%	10.4	25.5	59.1	5		2	36.3	22.1	39.6	
16	18	1300	8 51	832	ppm	20 3	32.9	201 6	22.5		16.7	279.5	152.7	146.7	
					epm	1	2.7	8.8	0.6	13.1	0.3	4.6	3.2	4.1	12.17
					epm%	7 8	20.9	66.9	4.4		2.3	37.6	26.1	33.9	
17	19	5400	8 48	3456	ppm	65 5	132.3	861.7	92.2		39.4	330.5	1061	1101	
					epm	3.3	11	37 5	2.4	54.12	0.7	5.4	22.1	31	59 19
					epm%	6.1	20.4	69.2	4.4		1.1	9.2	37.3	52.4	
18	20	1370	8 49	877	ppm	31 5	58.1	190.1	38.5		22.7	257.6	186 3	194.8	
					epm	1 6	4 8	8.3	1	15.67	0.4	4.2	3.9	5 5	13.97
					em%	10.1	30 9	52.5	6.3		2.7	30.2	27.8	39.3	

Ser. No.	Well No.	EC	pH	TDS	Untis	Ca++	Mg++	Na+	K+	Sum Cat.	CO3--	HCO3-	SO4--	Cl-	Sum Ani.
19	21	920	8.42	589	ppm	22.1	39	118.8	26.4		17.9	246.7	90.5	89.3	
					epm	1.1	3.3	5.2	0.7	10.2	0.3	4	1.9	2.5	8.74
					epm%	10.8	31.9	50.7	6.6		3.4	46.3	21.6	28.8	
20	22	1190	8.54	762	ppm	22.1	43.7	168.6	27		19.1	279.5	177.3	112.4	
					epm	1.1	3.6	7.3	0.7	12.77	0.3	4.6	3.7	3.2	11.76
					epm%	8.6	28.5	57.4	5.4		2.7	39	31.4	26.9	
21	23	1310	8.48	838	ppm	21	42.5	190.2	26.2		20.3	286.8	165.3	136.1	
					epm	1.1	3.6	8.3	0.7	13.54	0.3	4.7	3.4	3.8	12.32
					epm%	7.8	26.2	61.1	5		2.8	38.2	28	31.1	
22	24	3020	8.37	1933	ppm	25.9	57.8	452.6	40.2		27.5	307.5	2.1	719.6	
					epm	1.3	4.8	19.6	1	26.82	0.5	5	0	20.3	25.81
					epm%	4.8	18	73.4	3.8		1.8	19.5	0.2	78.5	
23	26	920	8.45	589	ppm	23.4	50.8	96.3	31.1		19.9	218.7	79.3	107.5	
					epm	1.2	4.2	4.2	0.8	10.39	0.3	3.6	1.7	3	8.57
					epm%	11.3	40.8	40.3	7.7		3.5	41.9	19.3	35.4	
24	28	4000	8.13	2560	ppm	117	196.9	346.8	144.5		8.4	126.4	806.4	1016.5	
					epm	5.9	16.4	15.1	3.7	41.05	0.1	2.1	16.8	28.6	47.64
					epm%	14.3	40	36.7	9		0.3	4.4	35.3	60.1	
25	29	2750	8.3	1760	ppm	73.6	132.8	264.2	92.6		13.2	151.9	449.2	544	
					epm	3.6	11.1	11.5	2.4	28.61	0.2	2.5	9.4	15.3	27.39
					epm%	12.9	36.7	40.2	8.3		0.8	9.1	34.2	55.9	
26	30	3720	7.56	2381	ppm	73.5	170.2	394	134.1		21.5	279.5	698.8	720.6	
					epm	3.7	14.2	17.1	3.4	38.43	0.4	4.6	14.6	20.3	39.8
					epm%	9.6	36.9	44.6	8.9		0.9	11.5	36.6	51.1	
27	31	2060	7.77	1318	ppm	51.4	106.6	208.2	70.4		8.4	164.1	242.4	387.4	
					epm	2.6	8.9	9.1	1.8	22.31	0.1	2.7	5.1	10.9	18.79
					pm%	11.5	39.8	40.6	8.1		0.7	14.3	26.9	58.1	

Ser. No.	Well No.	EC	pH	TDS	Untis	Ca++	Mg++	Na+	K+	Sum Cat.	CO3–	HCO3-	SO4–	Cl-	Sum Ani.
28	32	3890	8.24	2490	ppm	97.1	185	387.4	139.6		16.7	188.4	557	1032.3	
					epm	4.9	15.4	16.8	3.6	40.7	0.3	3.1	11.6	29	44.05
					epm%	11.9	37.9	41.4	8.8		0.6	7	26.3	66	
29	33	3610	7.7	2310	ppm	100.9	181.1	353.4	127.9		8.4	184.7	698.2	811.5	
					epm	5.1	15.1	15.4	3.3	38.79	0.1	3	14.6	22.9	40.57
					epm%	13	38.9	39.6	8.5		0.3	7.5	35.9	56.3	
30	35	1150	7.8	736	ppm	28.7	43	148.8	26.8		14.3	194.4	99.1	179.3	
					epm	1.4	3.6	6.5	0.7	12.18	0.2	3.2	2.1	5.1	10.54
					epm%	11.7	29.5	53.1	5.6		2.3	30.2	19.6	47.9	

Ser. No.	Well No.	F	Sr	Cr	Fe	Zn	Cu	Co	Ba	NO3
1	1	0.85	1.59	0.18	0.00	0.15	0.11	0.00	0.03	2.27
2	2	3.24	16.35	0.03	0.12	0.16	0.08	0.08	0.03	9.17
3	3	0.52	1.58	0.07	0.00	0.31	0.05	0.02	0.05	1.13
4	4	0.68	1.87	0.10	0.04	0.17	0.18	0.00	0.14	1.67
5	5	0.27	0.94	0.05	0.00	0.04	0.08	0.00	0.03	2.98
6	6	0.64	4.42	0.01	0.03	0.32	0.14	0.00	0.05	37.36
7	7	0.35	1.41	0.05	0.03	0.09	0.10	0.03	0.04	2.18
8	10	1.65	4.69	0.04	0.06	0.16	0.10	0.05	0.00	11.69
9	11	1.52	5.58	0.00	0.12	2.18	0.11	0.00	0.08	10.16
10	12	1.42	5.29	0.05	0.00	0.45	0.07	0.05	0.01	10.86
11	13	4.64	11.95	0.03	0.07	0.12	0.03	0.11	0.00	5.23
12	14	1.00	4.27	0.00	0.30	0.02	0.18	0.05	0.03	1.90
13	15	0.64	1.24	0.05	0.04	0.03	0.00	0.03	0.01	1.81
14	16	1.87	3.95	0.10	0.10	0.04	0.07	0.00	0.03	2.76
15	17	0.55	1.10	0.04	0.09	0.10	0.00	0.03	0.01	1.63
16	18	0.61	1.12	0.10	0.03	0.04	0.04	0.05	0.00	1.53
17	19	2.04	4.25	0.01	0.00	0.42	0.12	0.00	0.04	39.14
18	20	0.52	1.75	0.00	0.10	0.19	0.03	0.02	0.04	1.70
19	21	0.45	0.88	0.07	0.00	0.11	0.04	0.03	0.04	1.54
20	22	0.51	0.96	0.00	0.33	0.06	0.04	0.05	0.01	1.68
21	23	0.59	0.91	0.11	0.14	0.08	0.03	0.05	0.00	1.43
22	24	1.61	3.25	0.03	0.07	0.09	0.23	0.03	0.01	1.85
23	26	0.35	0.75	0.01	0.09	0.00	0.08	0.12	0.03	2.59
24	28	1.48	7.15	0.04	0.07	0.16	0.05	0.03	0.09	7.53
25	29	0.86	4.06	0.16	0.03	0.09	0.03	0.00	0.14	17.09
26	30	1.35	5.05	0.05	0.01	0.18	0.10	0.08	0.09	36.63
27	31	0.68	2.69	0.01	0.01	0.07	0.08	0.11	0.14	12.43
28	32	1.32	5.22	0.03	0.06	0.04	0.14	0.06	0.07	14.41
29	33	1.29	5.27	0.08	0.10	0.05	0.12	0.05	0.04	16.12
30	35	0.44	0.91	0.12	0.03	0.04	0.04	0.05	0.03	1.48

APPENDIX C

Part 1

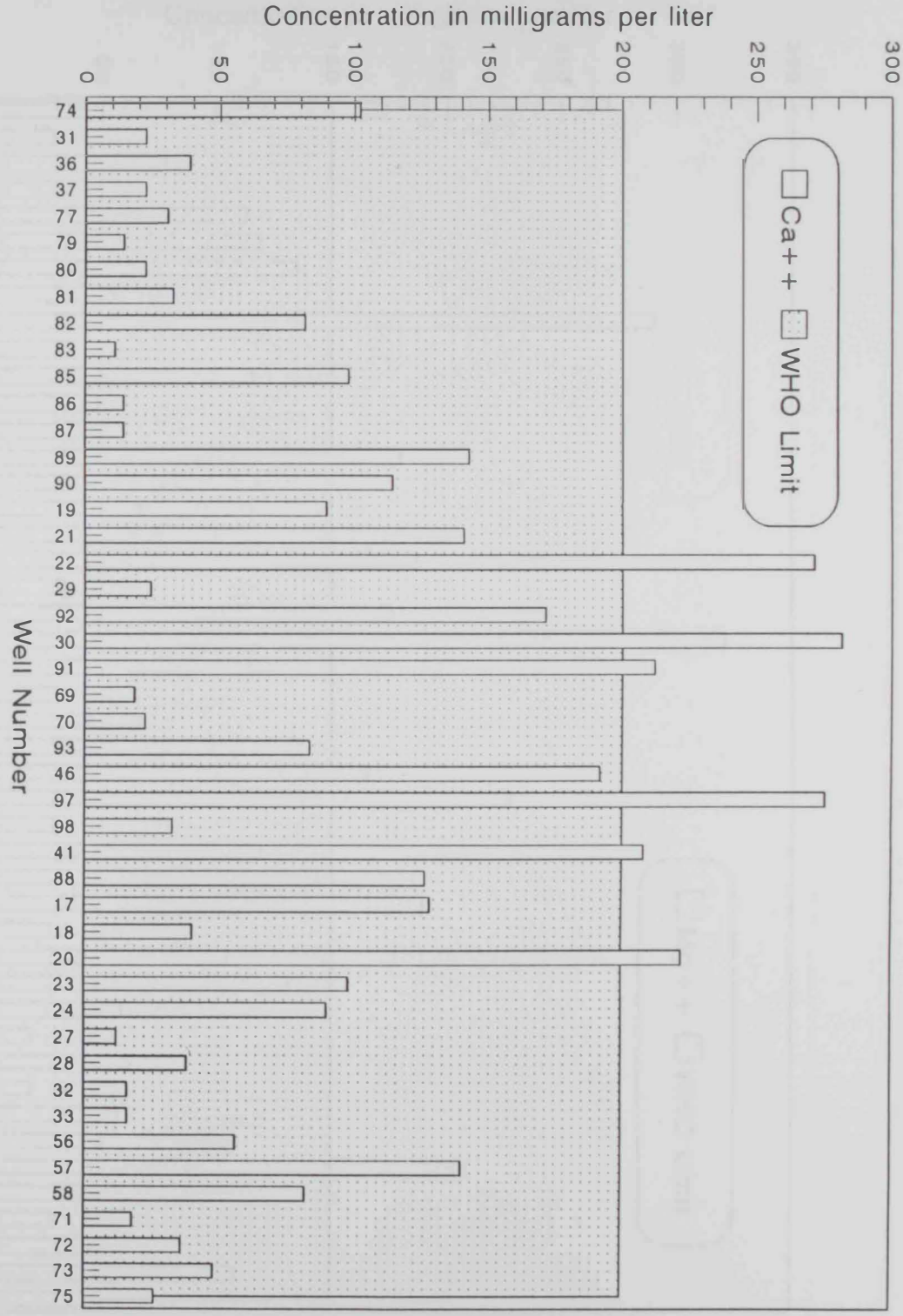
Comparison between

the concentrations of some major and trace chemical constituents

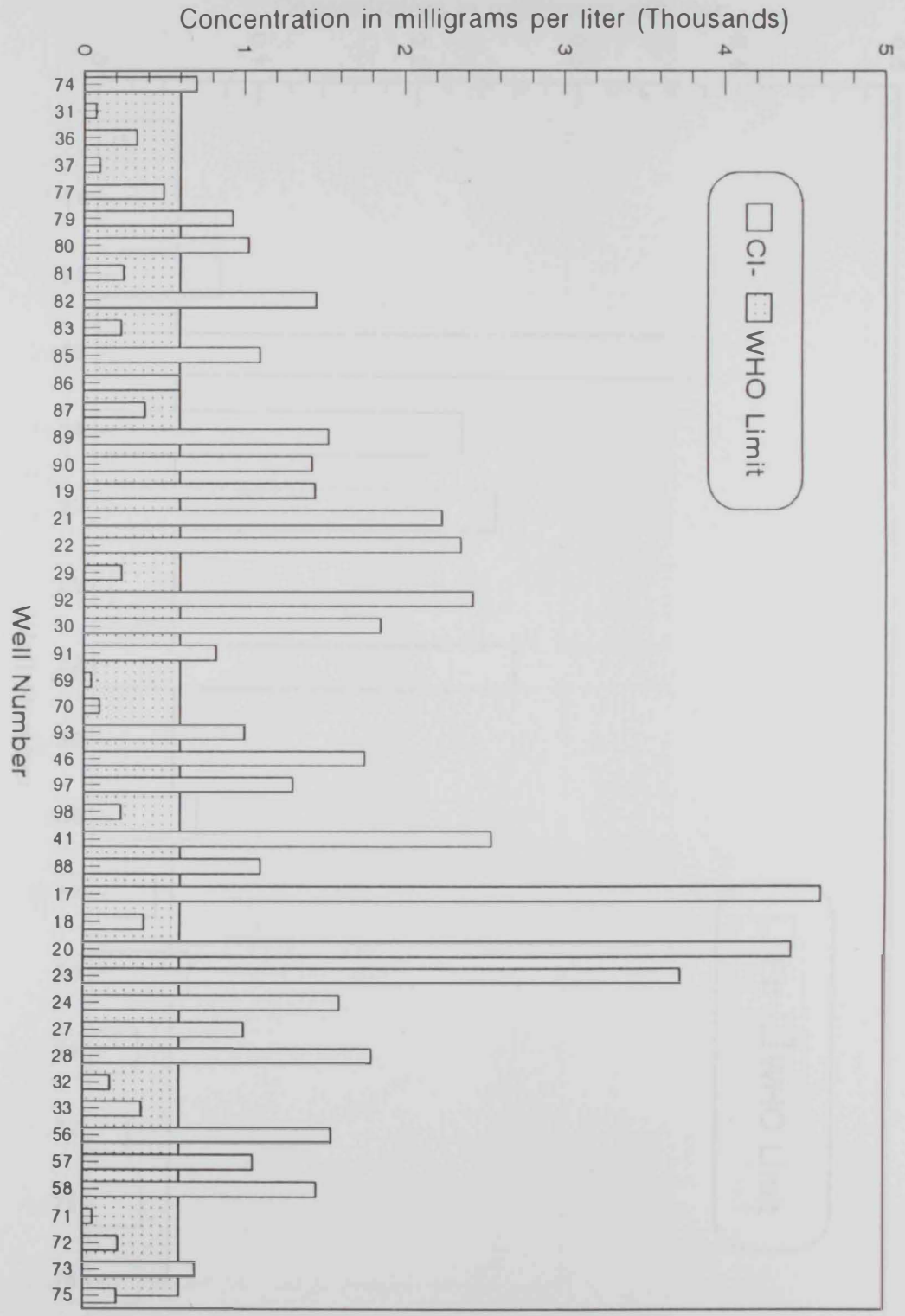
in Al Ain Groundwater during February 1995

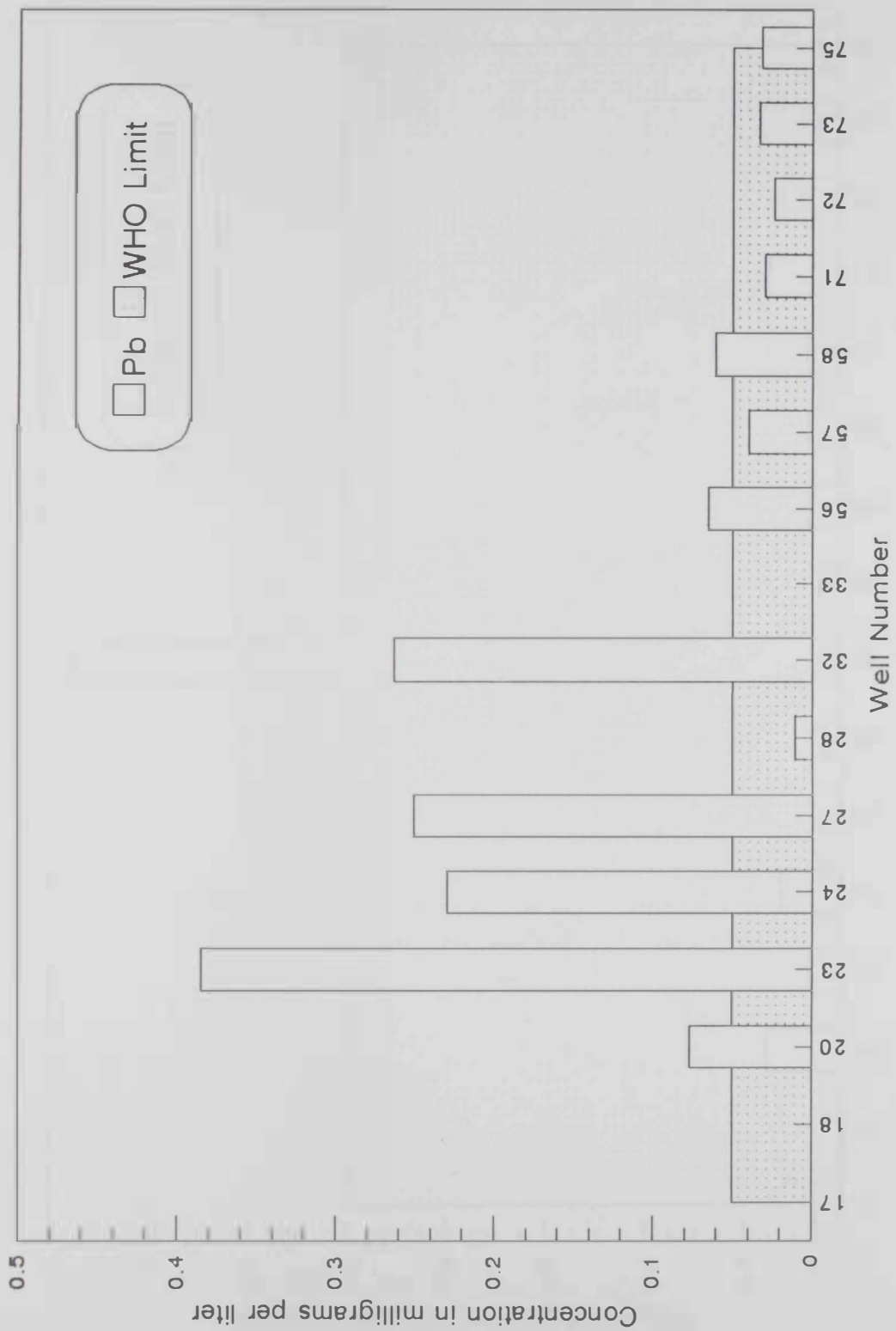
with the WHO (1971) standards for drinking water

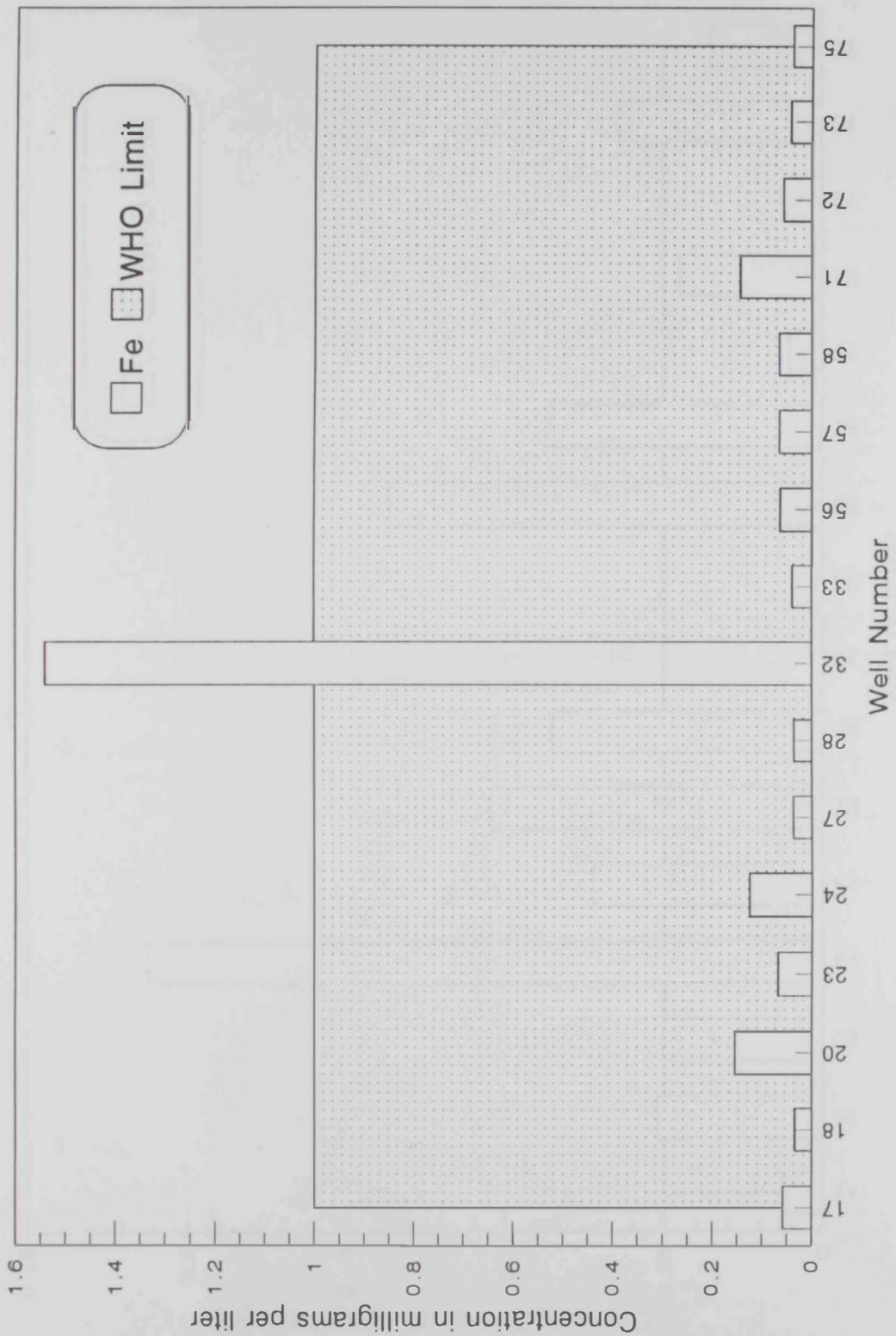
Concentration in milligrams per liter (Thousands)
0
1
2
3
4
5
Well Number
74
31
36
37
77
79
80
81
82
83
85
86
87
89
90
19
21
22
29
92
30
91
69
70
93
46
97
98
41
88
17
18
20
23
24
27
28
32
33
56
57
58
71
72
73
75
Ca++
Mg++
Na+
K+
CO3-
HCO3-
SO4--
Cl-


Concentration in milligrams per liter
0
50
100
150
200
250
300
Ca++
WHO Limit
Well Number
74
31
36
37
77
79
80
81
82
83
85
86
87
89
90
19
21
22
29
92
30
91
69
70
93
46
97
98
41
88
17
18
20
23
24
27
28
32
33
56
57
58
71
72
73
75


Concentration in milligrams per liter
0
50
100
150
200
250
300
350
Well Number
74
31
36
37
77
79
80
81
82
83
85
86
87
89
90
19
21
22
29
92
30
91
69
70
93
46
97
98
41
88
17
18
20
23
24
27
28
32
33
56
57
58
71
72
73
75
Mg++
WHO Limit


Concentration in milligrams per liter (Thousands)
0
1
2
3
4
5
Well Number
74
31
36
37
77
79
80
81
82
83
85
86
87
89
90
19
21
22
29
92
30
91
69
70
93
46
97
98
41
88
17
18
20
23
24
27
28
32
33
56
57
58
71
72
73
75
Cl-
WHO Limit


Pb
WHO Limit
Concentration in milligrams per liter
0.5
0.4
0.3
0.2
0.1
0
Well Number
17
18
20
23
24
27
28
32
33
56
57
58
71
72
73
75


Fe
WHO Limit
Concentration in milligrams per liter
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Well Number
17
18
20
23
24
27
28
32
33
56
57
58
71
72
73
75

Cr
WHO Limit
Concentration in milligrams per liter
0.25
0.2
0.15
0.1
0.05
0
Well Number
17
18
20
23
24
27
28
32
33
56
57
58
71
72
73
75

APPENDIX C

Part 2

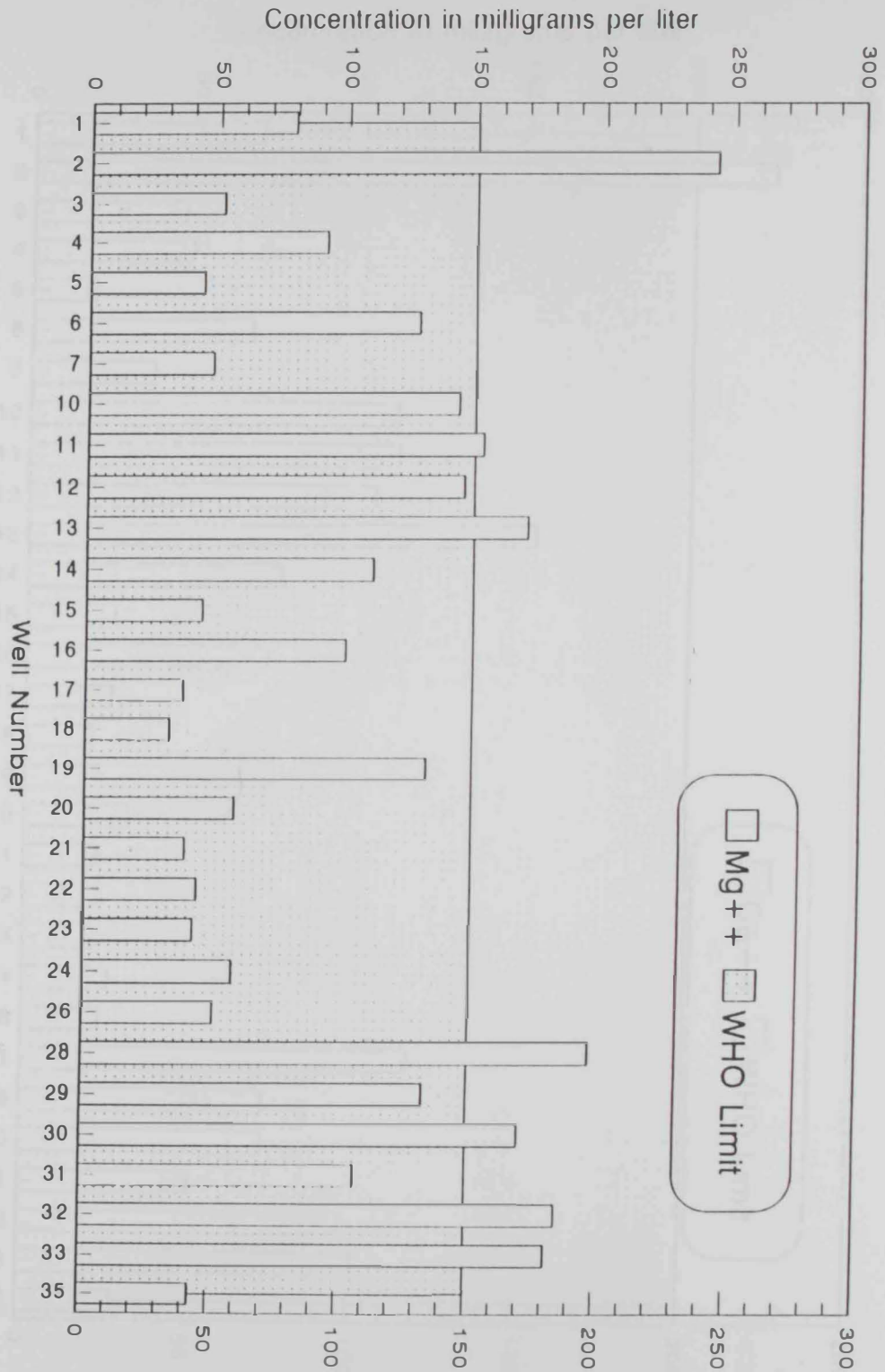
Comparison between

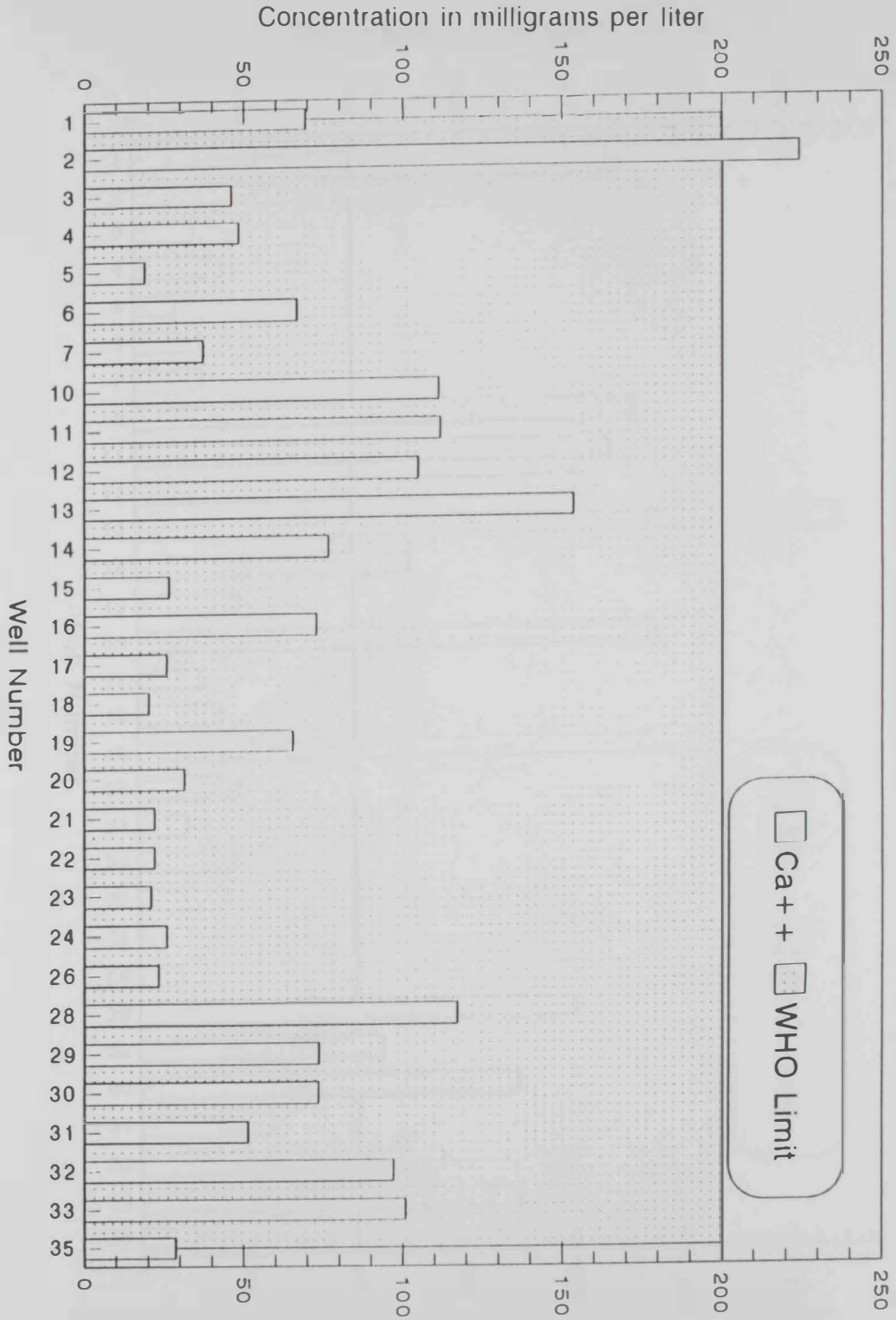
the concentrations of some major and trace chemical constituents

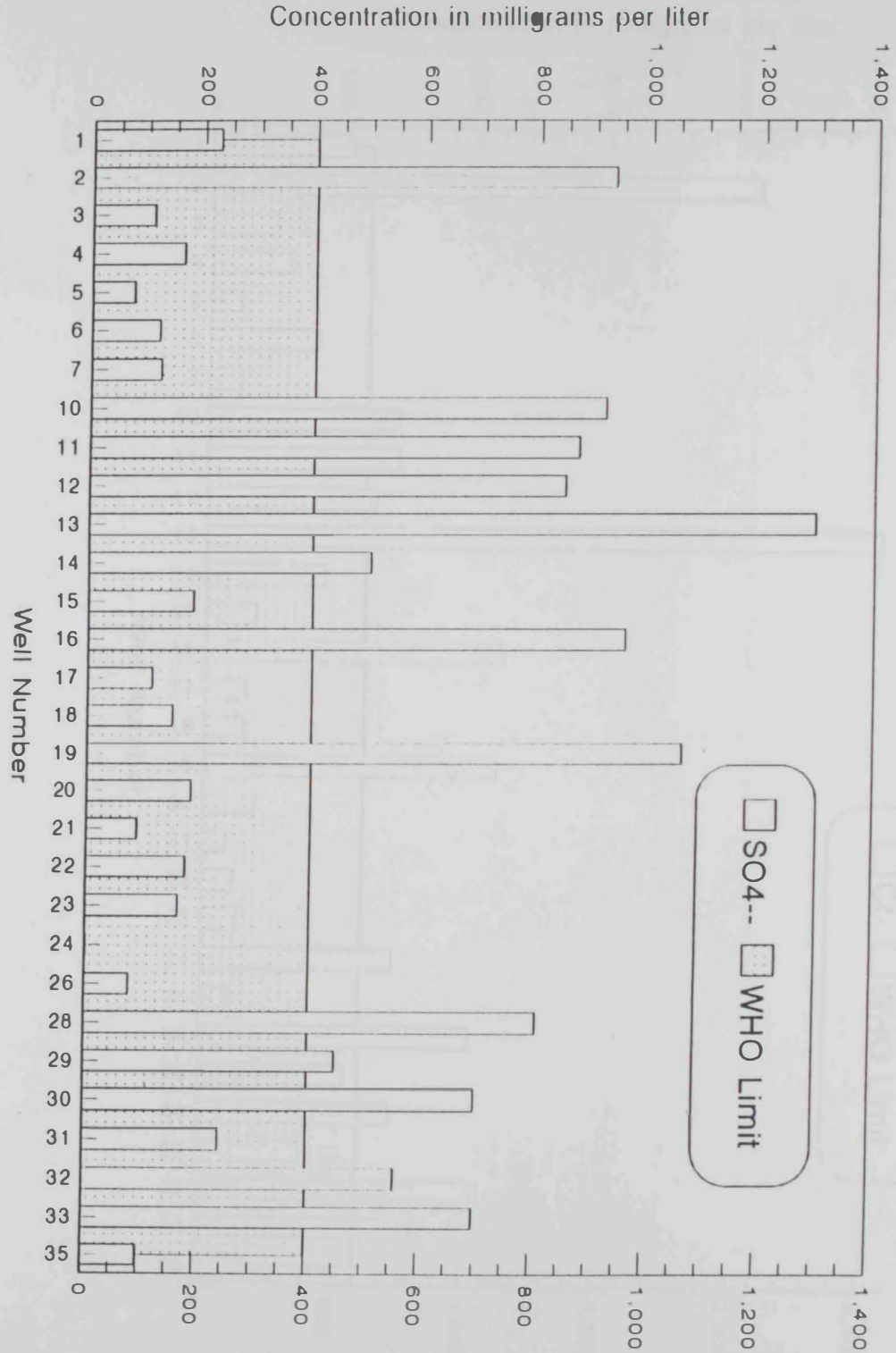
in Al Oha Groundwater during March 1996

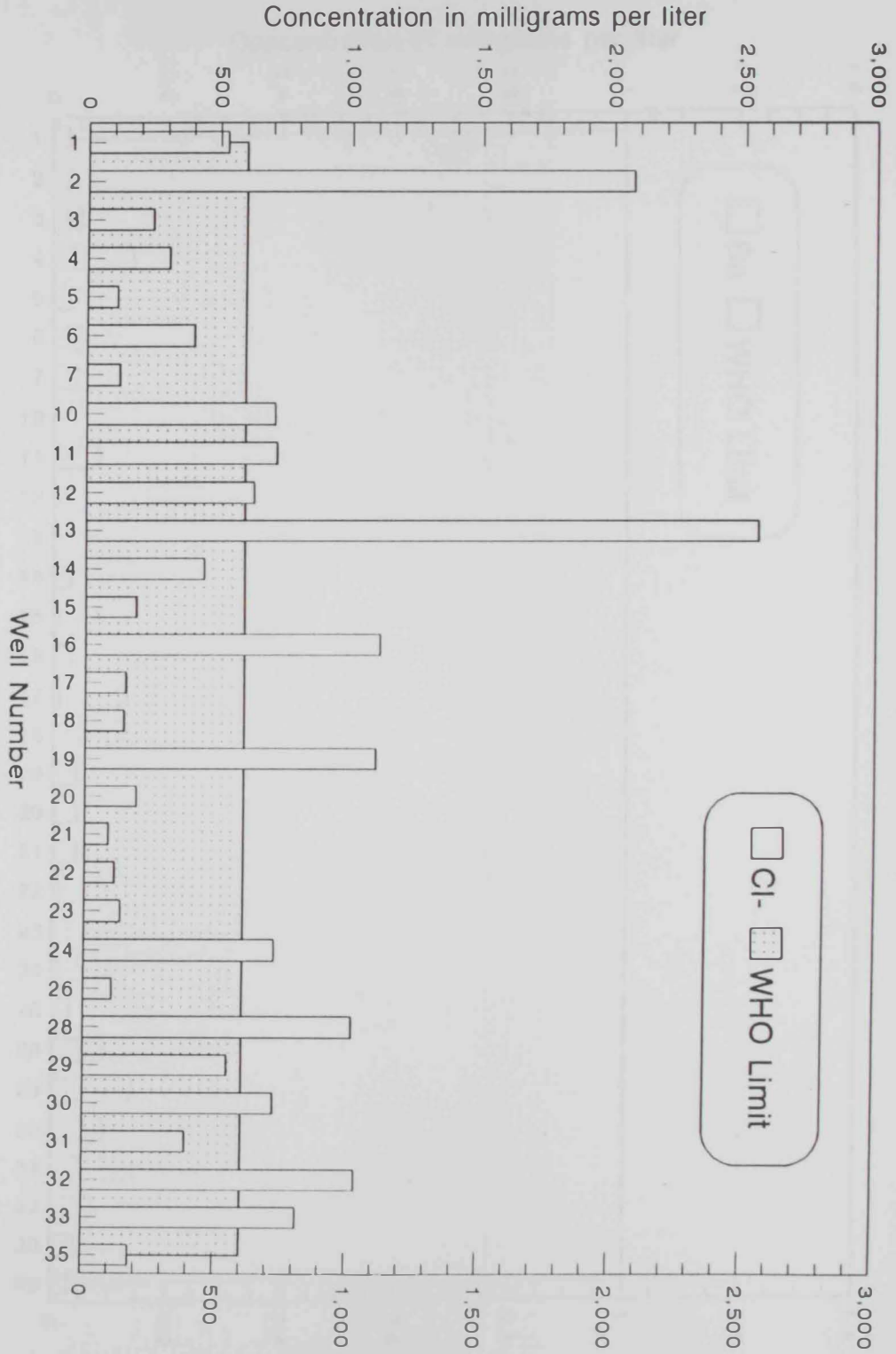
with the WHO (1971) standards for drinking water

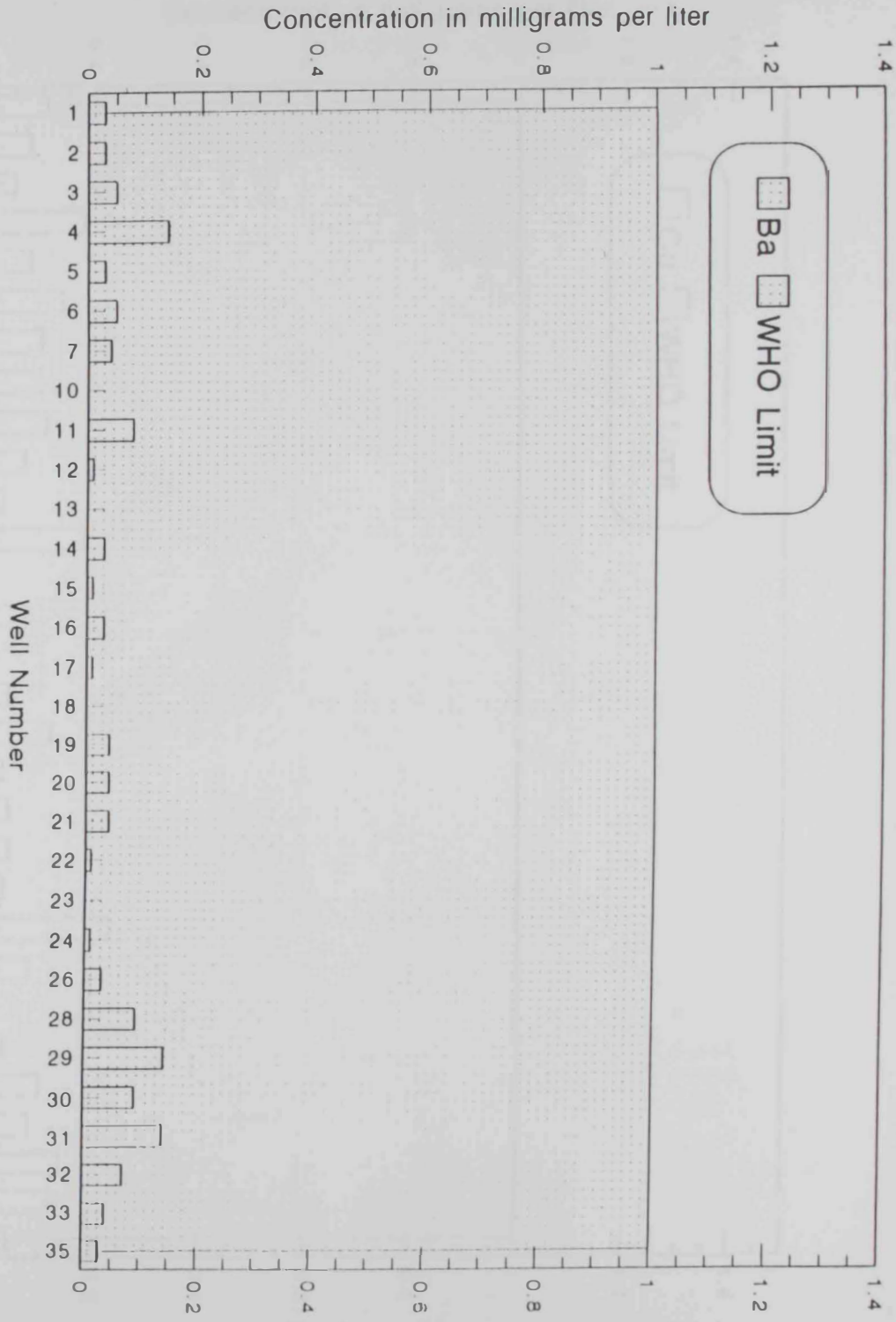
Concentration in milligrams per liter
0
500
1,000
1,500
2,000
2,500
3,000
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35
Ca++
Mg++
Na+
K+
CO3--
HCO3-
SO4--
Cl-

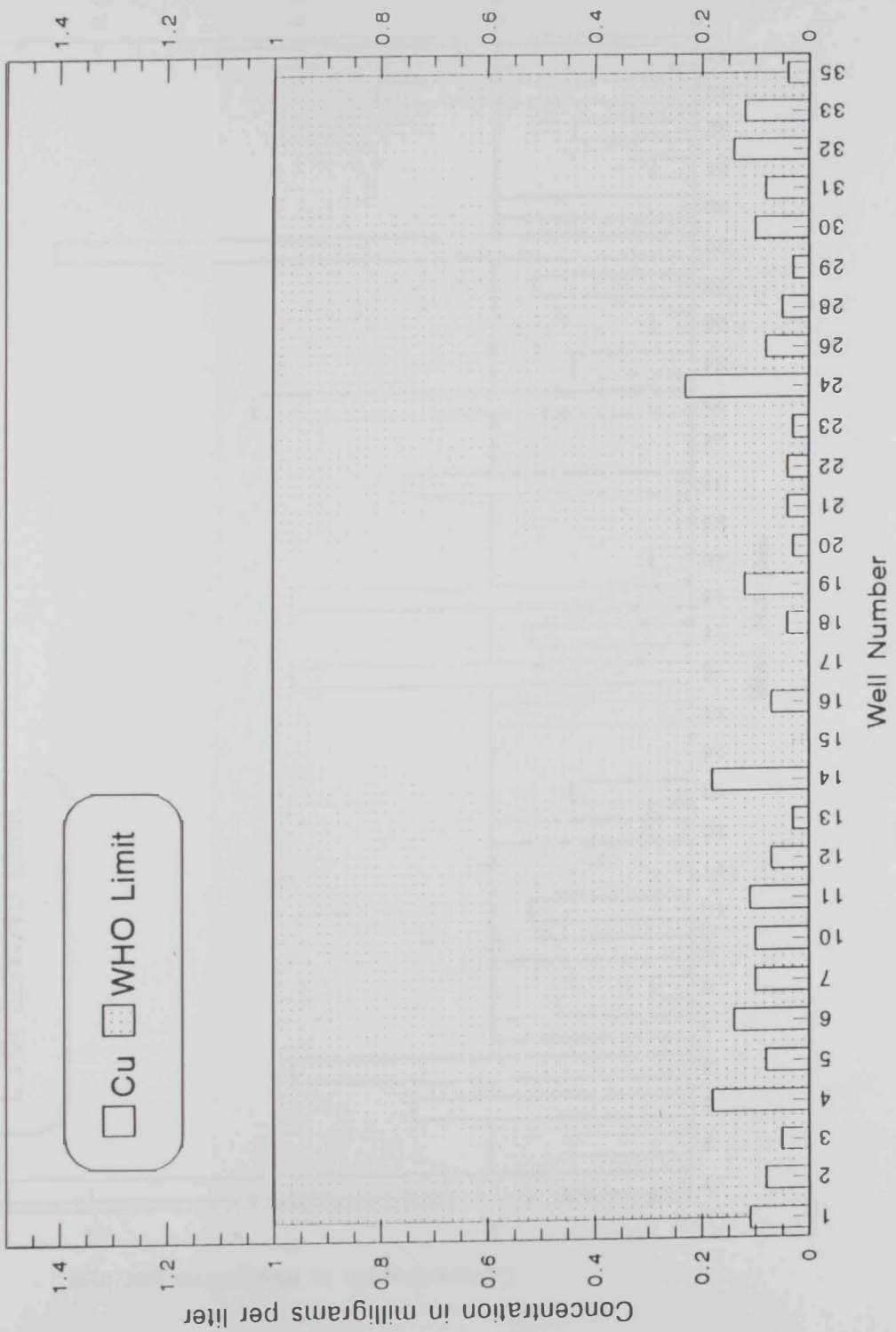

Concentration in milligrams per liter
0
50
100
150
200
250
300
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35
Mg++
WHO Limit

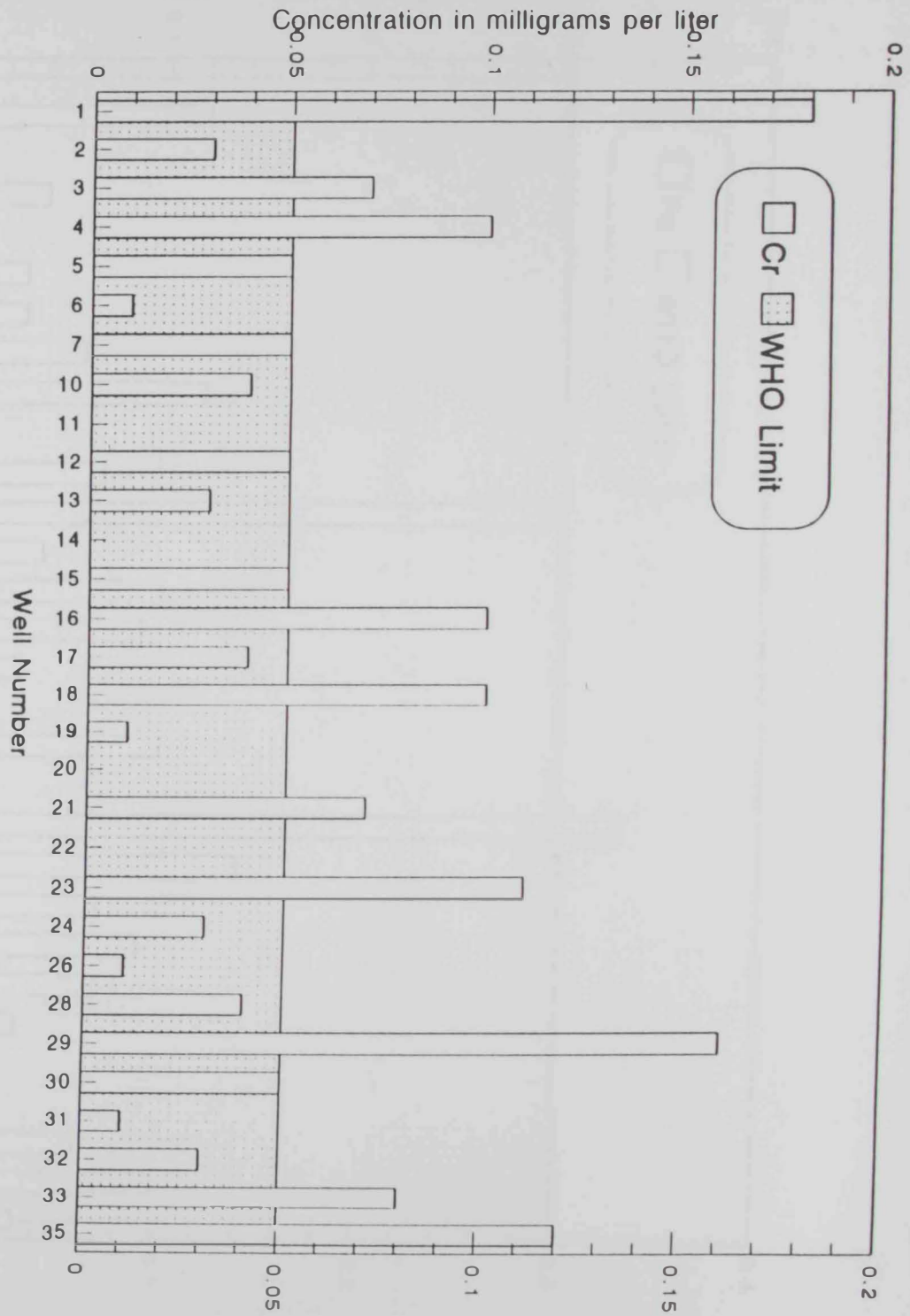

Concentration in milligrams per liter
0
50
100
150
200
250
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35
Ca++
WHO Limit

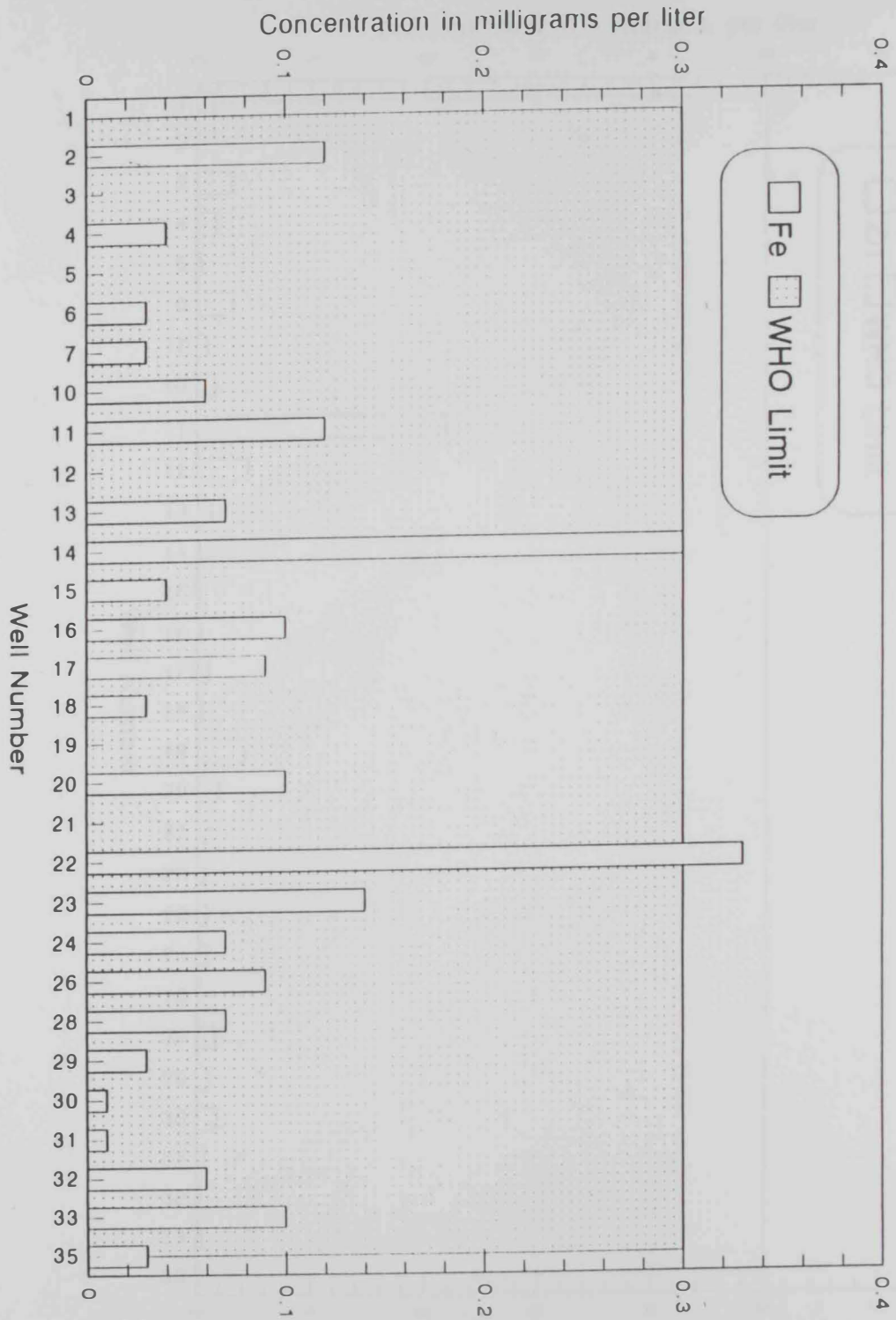

Concentration in milligrams per liter
0
200
400
600
800
1,000
1,200
1,400
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35
SO4--
WHO Limit

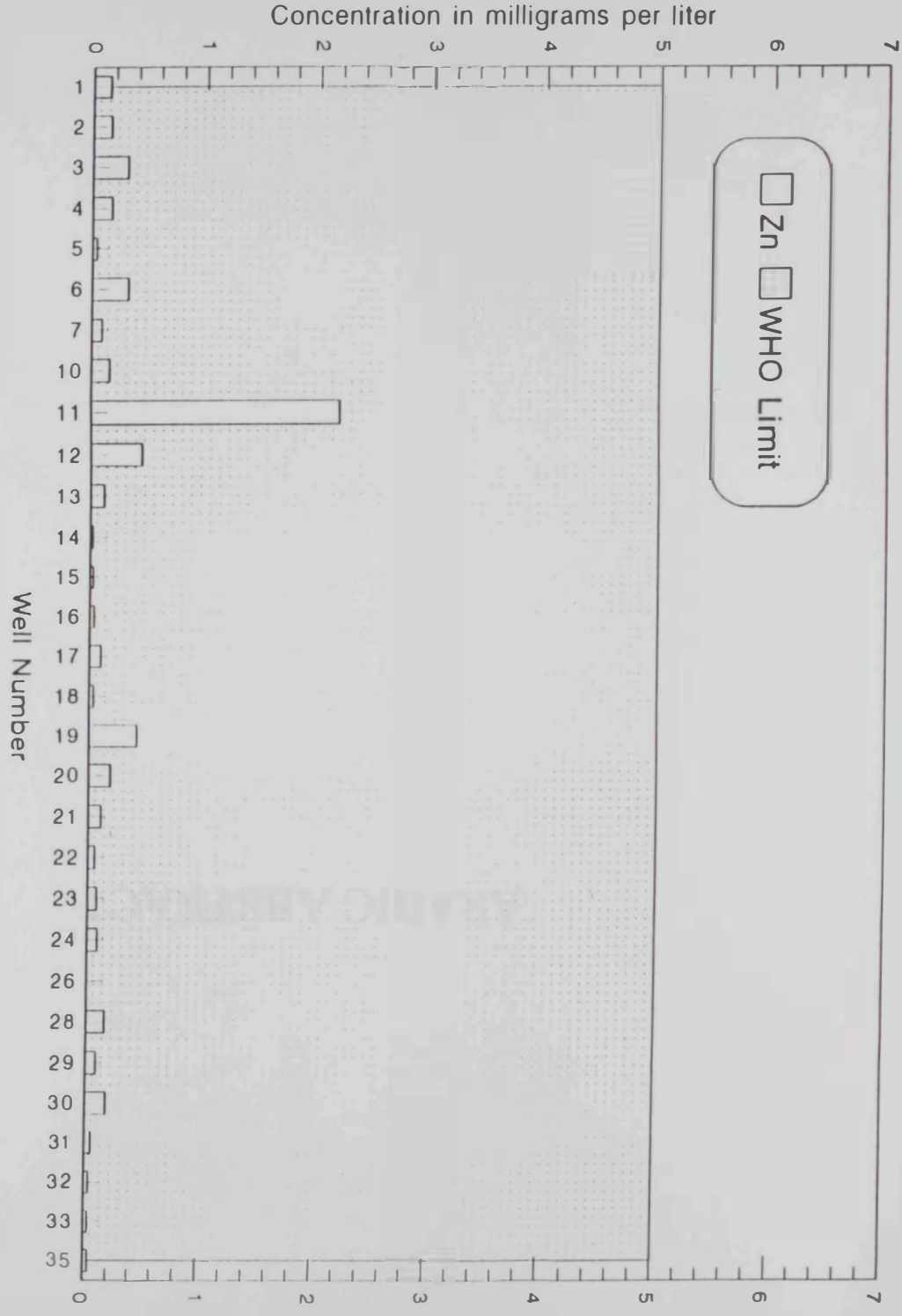

Concentration in milligrams per liter
0
500
1,000
1,500
2,000
2,500
3,000
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35
Cl-
WHO Limit


Concentration in milligrams per liter
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Ba
WHO Limit
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35


Cu
WHO Limit
Concentration in milligrams per liter
Well Number
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35


Concentration in milligrams per liter
0
0.05
0.1
0.15
0.2
Cr
WHO Limit
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35


Concentration in milligrams per liter
0
0.1
0.2
0.3
0.4
Fe
WHO Limit
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35


Concentration in milligrams per liter
0
1
2
3
4
5
6
7
Zn
WHO Limit
Well Number
1
2
3
4
5
6
7
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
26
28
29
30
31
32
33
35

ARABIC ABSTRACT

١٦- بالنسبة لملوحة المياه الجوفية فان مياه الجزء الشمالي الشرقي من منطقة العين يمكن أن تستخدم في ري كل أنواع المحاصيل الزراعية والمياه الجوفية في الهير والعوهة وسهل الجاو تعتبر مناسبة لرى العديد من المحاصيل . أما المياه الجوفية في غرب منطقة الدراسة فأنها لا تصلح لرى المحاصيل عدا تلك التي تتحمل الملوحة العالية . أما في الجزء الشمالي الغربي ، حول سويحان ، فان المياه الجوفية لا تصلح للرى تحت ظروف التربة ذات الصرف الجيد .

١١- تم قياس تركيزات البار يـوم والكروميـوم والنحـاس والحديـد والرصـاص والمنجنيز والزنك والفلور والاسترونشيوم في عينات المياه التي جمعت في فبراير ١٩٩٥ . وجد أن تركيزات معظم هذه العناصر تحـت المستويات التي حددتها منظمة الصحة العالمية لمياه الشرب . عدا بعض الآبـار التي تتعدى فيها تركيزات بعض عناصر تلك المستويات ، خاصة تلك التي تقع في المنطقة الغربية .

١٢- أوضحت مقارنة المواصفات القياسية لمنظمة الصحة العالمية ودول مجلس التعاون الخليجي إن المياه الجوفية في الخزان المائي للعصر الرباعي في منطقتي العين والعوهة تصلح لأغراض الشرب .

١٣- طبقا لكمية الأملاح الذائبة الكلية في المياه الجوفية يمكن تقسيم المياه في منطقة العين إلى عذبه في الشرق ومختلطة في الوسط ومالحة في الغرب ، وتقع منطقة العوهة في منطقة المياه العذبة.

١٤- باستثناء الجزء الشمالي الشرقي من منطقة الدراسة فان المياه الجوفية في الخزان المائي للعصر الرباعي في منطقة العين تتميز بأنها عسره إلى عسرة جدا وتحتاج إلى معالجة قبل استخدامها في الأغراض المنزلية .

١٥- طبقا لنسبة أد مصاص الصوديـوم فـان الميـاه الجوفيـة في شـرق منطقـة الدراسة لها تأثير ضار محدود على النباتات والتربة ، و في المنطقة المتوسطة يمكن أن يسبب استخدام المياه الجوفية في الري إلى أضرار متوسطة . آمـا في المنطقة الغربية خاصة حول سويحان ، فان استخدام المياه في أغراض الري يمكن أن يسبب أضرار كبيرة للنباتات والتربة معا .

الجوفية فانها ترتبط بالسحب الشديد للمياه الجوفية علاوة على تسرب مياه الري ذات نسبة الأملاح المرتفعة نسبيا .

٨- كان ترتيب الأيونات السالبة للمياه الجوفية لشرق منطقة العين في فبراير ١٩٩٥ كما يلي : البيكربونات فالكلوريدات ثم الكبريتات تليها الكربونات . أما في الغرب فكان الترتيب : الكلوريدات ثم الكبريتات فالبيكربونات تليها الكربونات . في مارس ١٩٩٦ ، كان ترتيب الأيونات السالبة في الشرق على النحو التالي : البيكربونات ثم الكبريتات فالكلوريدات تليها الكربونات . أما في الغرب فكانت : الكلورايدات ثم الكبريتات فالبيكربونات تليها الكربونات . وهنا يزداد تركيز كل الايونات من الشرق نحو الغرب في اتجاه حركة المياه الجوفية .

٩- ما عدا البئر رقم ٥٧ على طريق العين ابوظبي ، يعتبر تركيز أيون النترات في منطقتي العين والعوهة اقل من النسبة المسموح بها من قبل منظمة الصحة العالمية لمياه الشرب . ربما لان عمق الماء الجوفي في منطقة العوهة لا يقل عن ٣٠ متر وان معدل الأمطار السنوية لا يتعدى ١٠٠ مم بالإضافة إلى استخدام تقنيات الري الحديثة وانخفاض معدل تغذية المياه الجوفية وكل هذه العوامل لا تساعد على غسيل تركيزات عالية من النترات من نطاق التربة إلى الخزان المائي للعصر الرباعي تحت منطقة الدراسة .

١٠- تراوح تركيز أيون الفوسفات في عينات المياه الجوفية التي تم جمعها من منطقة الدراسة في فبراير ١٩٩٥ بين نصف ملليجرام وملليجرام في اللتر . ورغم إن الأسمدة الفوسفاتية تستخدم بنفس المعدلات التي تستخدم فيها الأسمدة الازوتية فانة لا توجد مشكلة تلوث بالفوسفات وذلك لقدرة التربة على أد مصاص أيون الفوسفات بينما النترات تتحرك مع المياه بنفس سرعتها دون تفاعل آو أد مصاص ، خاصة إذا تميز الخزان المائي بوفرة عنصر الأوكسجين .

٣-المتوسطات السنوية لدرجة الحرارة والرطوبة النسبية والبخر والأمطار في منطقة الدراسة هي ٢٨ درجة منوية و ٥٠٪ و ٣٦٥٠ مم و ١٠٠ مم على التوالى.

٤- يبلغ عمق الماء الجوفي في منطقتي العين والعوهة ٩٠ و ٣٠ متر على الترتيب . كما يتغير الجهد الهيدروليكي من ٣٠٠ متر فوق مستوى سطح البحر شرق منطقة العوهة إلى ١٥٠ متر إلى الغرب من مدينة العين . وقد سبب الضخ الشديد للمياه الجوفية في نشوء مخروطي انخفاض يقع مركز أحدهما غرب مدينة العين والمركز الآخر شرق مدينة سويحان .

٥- يبلغ متوسط معامل النقل للخزان المائي للعصر الرباعي في منطقة العوهة ٥٢٠٠ متر مربع في اليوم كما يبلغ معامل الخزن حوالي ٠,٠٠٠٥

٦- تراوحت الكمية الكلية للأملاح الذائبة في الماء بين ٥٠٠ ملليجرام في اللتر في منطقة العوهة في الشمال الشرقي و ٦٠٠٠ ملليجرام في اللتر في الجنوب الشرقي ويدل ارتفاع معدل ملوحة المياه الجوفية في منطقة العين إلى تأثير الضخ الشديد للمياه الجوفية وضعف معدل تغذية الخزان المائي . ويتعدى تركيز الأملاح الذائبة الكلية في منطقة العوهة المعدلات التي وضعتها منظمة الصحة العالمية في بعض الآبار ، خاصة تلك التي تقع في غرب منطقة الدراسة .

٧- يدل ترتيب الأيونات الموجبة في المياه الجوفية إلى جمعت من المنطقة الشرقية بالعين في فبراير ١٩٩٥ أنها بدأت بالصوديوم يليه الماغنسيوم فالكالسيوم ثم البوتاسيوم أما المنطقة الغربية فترتيب الأيونات الموجبة هو الصوديوم فالكالسيوم يليه الماغنسيوم ثم البوتاسيوم . في مارس ١٩٩٦ ، أخذت الأيونات الموجبة الترتيب التالي : الصوديوم والماغنسيوم والكالسيوم فالبوتاسيوم . وتدل الخرائط الكنتورية لتوزيع الأيونات الموجبة أن هناك زيادة في تركيز تلك الأيونات من الشرق نحو الغرب ، في اتجاه حركة المياه الجوفية . أما الزيادات المحلية في درجة ملوحة المياه

الملخص العربى

يمثل الاستخدام المكثف للمخصبات الكيميائية في الأغراض الزراعية تهديدا لموارد المياه الجوفية ، خاصة الضحلة منها . ونظرا للزيادة المستمرة في الرقعة الزراعية بالإمارات العربية المتحدة وما يصاحبها من زيادة كمية المخصبات الكيميائية فان هذه الأطروحة تهدف إلى تقييم جودة المياه الجوفية في الخزانات المائية الطبيعية تحت الأراضي الزراعية في منطقة العوهة بالإمارات العربية المتحدة .

ولتحقيق أهداف الدراسة جمعت بيانات الأرصاد الجوية من محطة أرصاد العوهة والمحطات المجاورة للفترة من ١٩٧١ حتى ١٩٩٥ . كما جمع ٨٢ عينة مياه من الخزان المائي الجوفي لعصر البليستو سين من منطقتي العين والعوهة في فبراير ١٩٩٥ وفي مارس ١٩٩٦ وحللت العينات كيمائيا بالنسبة لمحتواها من الأيونات الرئيسية والثانوية في مركز رقابة الاغذية والبيئة ببلدية ابوظبى .

بناء على الدراسات الحقلية والمعملية والمكتبية على افلاج منطقة العين بالإمارات العربية المتحدة خلال الفترة من يناير ١٩٩٥ إلى مايو ١٩٩٦ يمكن تلخيص نتائج الدراسة الحالية في النقاط التالية :

١- أدى قرب منطقة الدراسة من جبال عمان ألتي تمثل مصدر التغذية الرئيسية للمياه الجوفية في الخزان المائي للعصر الرباعي إلي تأثير واضح على كمية وكيميائية ونوعية المياه . فالخزان المائي في منطقة الدراسة يستقبل تغذية سنوية قدرها ١٥ مليون متر مكعب من المياه العذبة ذات النوعية الجيدة .

٢- تسبب صعوبة إذابة مكونات الخزان المائي في منطقة الدراسة وضعف قابليتها للتفاعلات الكيميائية في ان المياه في الخزان المائي للعصر الرباعي في منطقة الدراسة تتميز بنوعية جيدة خاصة في العين والعوهة .

بسم الله الرحمن الرحيم

جامعة الامارات العربية المتحدة
كلية العلوم

عنوان الرسالة : تقويم جودة المياه الجوفية فى الخزانات المائية الطبيعية تحت الاراضى الزراعية فى منطقة العوهة ، الامارات العربية المتحدة.

اسم الباحث : وليد ناصر احمد بن بريك

لجنة التحكيم

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٢	أ.د. احمد محمود البرشمجى	استاذ كيمياء التربة مركز البحوث الزراعية وزارة الزراعة	
٣	د. حسن درويش	مدرس مصادر المياه كلية الهندسة جامعة الامارات	

تاريخ المناقشة : ١٩٩٧/٦/١٤.

بسم الله الرحمن الرحيم

جامعة الامارات العربية المتحدة
كلية العلوم

عنوان الرسالة : تقييم جودة المياه الجوفية في الخزانات المائية الطبيعية تحت الاراضى الزراعية فى منطقة العوهة ، الامارات العربية المتحدة.

اسم الباحث : وليد ناصر احمد بن بريك

المشرفون

مسلسل	الاسم	الوظيفة	التوقيع
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كلية العلوم

تقييم جودة المياة الجوفية فى الخزانات المائية الطبيعية تحت الاراضى الزراعية فى منطقة العوهة ، الامارات العربية المتحدة

رسالة مقدمة من الطالب

وليد ناصر احمد بن بريك

بكالوريوس فى العلوم الزراعية (تربة ، رى ، ميكنة)

١٩٩٣

استكمالا لمتطلبات الحصول على درجة الماجستير فى العلوم

(علوم البيئة)

كلية العلوم

جامعة الامارات العربية المتحدة

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